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Paleogene Nummulitid biostratigraphy of the Kohat and Potwar Basins in north-western Pakistan with implications for the timing of the closure of eastern Tethys and uplift of the western Himalayas

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ABSTRACT

The Paleogene larger benthic foraminifera (LBF) of the Kohat and Potwar basins, Pakistan are very useful in dating shallow marine sediments and cessation of marine sedimentation that provides constraint for crucial information on the initial age of India-Asia collision. We record important Paleogene LBF species in multiple sections of the two basins. We performed the biometric analysis of the nummulitid species useful for taxonomic purposes. We recognize six Larger Benthic Foraminiferal Zone (BFZ Zone 1-6) in the Kohat Basin. Among these Zones the first three (BFZ Zone 1-3) occur also in the Potwar Basin and the adjoining Trans Indus Ranges (TIR). The correlation of BFZ 1-6 Zones with the previous local and regional LBF biostratigraphic schemes in the Eastern Tethys (Pakistan-India) and Western Tethys (European Basins) resulted in recognition of useful index taxa for developing a regional stratigraphic framework during Paleogene. In the BFZ 1 Zone, The last occurrence (LO) of *Miscellanea miscella* and first occurrence (FO) of *Assilina dandotica* in the BFZ 2 Zone mark the Late Paleocene (Late Thanetian) - Early Eocene (Lower Illerdiuan1) Boundary. The co-occurrence of *A. pustulosa*, *Al. vredenburgi*, *Al. globula* and *Al. pasticillata* in the BFZ 2 Zone characterizes the Early Eocene (Lower Illerdiuan 1-Middle Illerdiuan 1) sediments. The synchronous FO of *N. atacicus* and *N. globulus* is an excellent global biostratigraphic marker of the Early Eocene (Middle Illerdiuan 1 - Middle Illerdiuan 2) Boundary and the FO of *O. complanatus* is a useful biostratigraphic marker for the Early Eocene (Lower Cuisian 2-Middle Cuisian) Boundary in the BFZ 3 Zone. Mammalian bones found at the base of Koldana Formation in the Kohat Basin represent Early

Eocene (Upper Cuisian), which is in agreement with the LBF biostratigraphy of the underlying Middle Cuisian strata. The FO of *A. exponens* in the BFZ 4 Zone record the Middle Eocene (Middle Lutetian 1) sediments while FO of *N. beaumonti* in the BFZ 5 Zone marks the Middle Lutetian 1-Middle Lutetian 2 Boundary. The FO of *A. cancellata* in the BFZ 6 Zone marks Middle Lutetian 2-Upper Lutetian Boundary.

The implications of our LBF study are that cessation of marine sedimentation in both Pakistani basins occurred in Early Eocene (Middle Cuisian \approx BFZ 3) around 50-49.5 Ma. Notably, marine conditions returned in the Kohat Basin in Middle Eocene (Middle Lutetian 1 \approx BFZ 4) due to an eustatic sea level rise. The final cessation of marine sedimentation, causing closure of the Eastern Tethys seaway in the Kohat Basin occurred in Middle Eocene (Upper Lutetian \approx BFZ 6) around 41.2 Ma, probably a result of some form of post-collisional stress.

INTRODUCTION

The Kohat and Potwar Basins form a Plateau in a structurally defined foreland fold and thrust belt, which is known as the Kohat and Potwar fold and thrust belt. The Kohat Plateau, an approximately 10,000 km² area of rugged anticlinal hills, is bounded to the north by the Main Boundary Thrust fault system (MBT) and to the south by the Trans-Indus Ranges (Pivnik and Wells 1996). The Kurram Fault and the Indus River form respectively the western and the eastern boundaries of the Plateau (Fig. 1). The Kohat Plateau contains highly deformed Precambrian-Cenozoic sedimentary rocks.

The Potwar Plateau has a width of 150 km in north-south direction (Kazmi and Rana 1982). It is bounded to the south by the Salt Range Thrust (SRT) and to the north by the Kalachitta-Margalla Hill Ranges. The Indus and the Jehlum rivers respectively mark the western and the eastern boundaries (Fig. 1). The deformed rocks in the northern part of the Potwar Plateau were designated as the Northern Potwar Deformed Zone (NPDZ) (Abbasi and McElroy 1991).

The Paleogene rocks of the Kohat Basin include clastic-carbonate mixed lithofacies of the Patala Formation, pelagic clays of Panoba Formation, Bahadur Khel Salt Facies, Jatta Gypsum Facies, carbonate-clastic mixed facies of Sheikhan Formation, red continental clays of Koldana Formation and the carbonate dominated sequence of Kohat Formation (Table 1). The Paleogene rocks of the Potwar Basin and adjacent Trans Indus Ranges (TIR) include carbonates of Lockhart Formation,

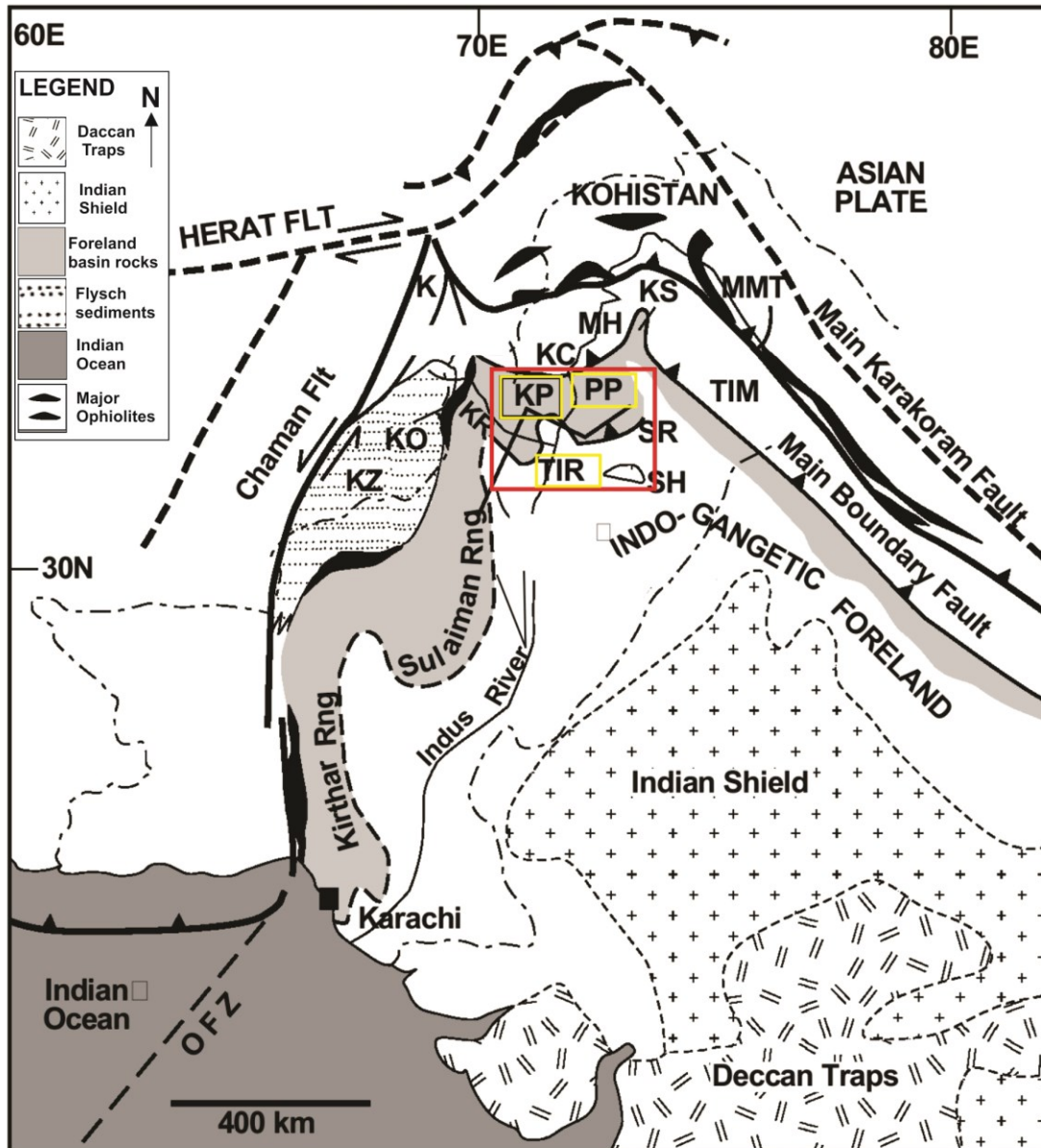


Fig. 1. Tectonic map of northern Pakistan (inset showing location of study area), showing the locations of the Asian Plate, the Kohistan Island Arc, the northern Indian continental margin (TIM), the undeformed Indo-Gangetic foreland and Indian Shield. Abbreviations are: K-Kabul Block; KC-Kala Chatta Range; KO-Khost Block; KP-Kohat Plateau; KR-Kurram River; KS-Kashmir Syntaxis; KZ-Katawaz Flysch Basin; MH-Margalla Hills; MMT-Main Mantle Thrust; OFZ-Owen Fracture Zone; PP-Potwar Plateau; SH-Sargodhah Hills; SR-Salt Range; TIR-Trans Indus Ranges modified after Treloar and Izzat (1993) and Pivnik and Wells (1996).

clastic-carbonate mixed lithofacies of Patala Formation and carbonates of Nammal, Sakessar and Chorgali formations (Table 1). The usage of Ranikot for Paleocene, Laki for Early Eocene (Noetling 1903), and Kirthar for Middle Eocene (Blanford 1878) in the Lower Indus Basin has been extended by previous workers (Vredenburg 1906, Davies 1940, Eames 1950, 1952, Nagappa 1959) to subdivide the Paleogene strata of the Kohat and Potwar Basins. Vredenburg (1906) established local biozones and described *N. millecaput* at the base of the upper Kirthar beds and *N. beaumonti* near the top of the upper Kirthar (Upper Middle Eocene) beds in the Kohat Basin. According to Vredenburg (1906) the lowest zone of upper Kirthar contains *A. spira*, and *N. perforatus* which continue into the overlying zone, while his third zone contains *N. complanatus*. Nuttal (1925, 1926) recorded age diagnostic foraminifera from the Laki Series of the Kohat Basin and classified them according to their septal filament types. Davies (1930, 1940) synonymises the species in Vredenburg (1906) Zone 1, *A. spira* with *A. papillata* and its larger derivative *A. irregularis*, *N. perforatus* with *N. obtusus* / *N. uroniensis* in Zone 2, and *N. complanatus* with *N. millecaput* in Zone 3. Davies (1940) claimed that there is no paleontological evidence to define an upper / middle Kirthar boundary in the Kohat Basin. Eames (1950) presented the local paleontological subdivisions and correlated the Eocene rocks of the Kohat Basin with the Rakhi Nala and Zinda Pir area in the Lower Indus Basin. He concluded that more work is needed to be done on collections from different facies of the Laki and Kirthar Series before any regional subdivision on paleontological grounds could be attempted. Gill (1953) described various Laki age Assilina species from the Kohat Basin. Nagappa (1959) and Pascoe (1963) reported Early Eocene Alveolina *oblonga*, *A. daviesi*, *A. laminosa*, *N. ataticus* and Orbitolites *complanatus* from the Kohat Basin. Kureshy (1975) provides an overview of the taxonomy and a range distribution of the larger benthic foraminiferal species recorded from different parts of Pakistan including a few representatives of the Laki and the Kirthar age from the Kohat Basin. Meissner et al. (1974) in a comprehensive studies of the Kohat Plateau also confirmed LBF of Eocene age. Roohi and Baqri (2004) reported Middle-Upper Eocene foraminiferal species from the Kohat Formation in the Kohat Basin. Different views exist about the development of upper Kirthar (Upper Middle Eocene) beds in the Kohat Basin. Davies (1940), Vredenburg (1906), Eames (1950,1952) and Roohi and Baqri (2004) support the existence of the upper Kirthar (Upper Middle

AGE			KOHAT	KALA CHITTA	HAZARA	POTWAR & TIR
MIOCENE			MUREE FORMATION			
OLIGOCENE			FATEHJANG MEMBER			
EOCENE	UPPER (PRIBONIAN)		UNCONFORMITY			
	MIDDLE (LUTETIAN)					
	LOWER (YPRESSIAN)		JATTA GYPSUM / SHEIKHAN FM BAHADUR KHEL SALT / PANOBA FM	CHORGALI FORMATION MARGALA HILL LIMESTONE	SAKESSAR FM NAMMAL FM	
PALEOCENE	UPPER	THANETIAN	PATALA FORMATION LOCKHART LIMESTONE			
	LOWER		HANGU FORMATION	FERRUGINOUS PISOLITE	HANGU FORMATION	
	DANIAN		UNCONFORMITY		FERRUGINOUS PISOLITE	
CRETACEOUS	UPPER	MAAST	KAWAGARH FORMATION		UNCONFORMITY	
		CAMP				
		SANT				
		CON				

Table 1: Cretaceous-Paleogene Lithostratigraphic framework of the Kohat Basin, Potwar Basin, Trans Indus Ranges (TIR) and adjoining Kala Chitta and Hazara area, NW Pakistan.

Eocene) strata while Gill (1953) and Meissner (1974) did not find any bed younger than the middle Kirthar (Lower Middle Eocene) in the Kohat Basin. The previous paleontological investigation related to the biostratigraphy of the Potwar Basin (Weiss 1988, 1993; Köthe et al. 1988; Afzal & Daniels, 1991; Butt, 1991; Weiss, 1993; Afzal, 1996; Afzal & Butt, 2000; Akhtar, M. & Butt, A.A., 2000; Sameeni & Butt, 2004; Afzal et al., 2005; Sameeni, 2009 and Gahzi et al. 2010) and Kohat Basin are well summarized in the work of Afzal et al (2009 & 2011). They have integrated, collated, and reinterpreted the dinoflagellate, nannofossil, planktonic foraminiferal and shallow benthonic foraminiferal biostratigraphical data for the Greater Indus Basin in Pakistan. In their work age-diagnostic LBF are illustrated only from the Late Paleocene Lockhart Formation. Therefore, in order to establish a more reliable and comprehensive LBF biostratigraphic scheme for the Kohat and Potwar Basins, in this paper, we aim to investigate the LBF in more detail for a

reliable biostratigraphic framework for the Paleogene strata in the two basins. A regional comparison of the LBF biostratigraphy of the study area with the Indian Basins (Govindon, 2003; Matsumaru & Sarma, 2010) and European Basins (Sierra-Kiel et al 1998) has also been attempted to test the LBF chronostratigraphic significance and implications for knowing the timing of the closure of eastern Tethys seaway in Pakistan.

MATERIAL AND METHODS

This study uses taxonomy of the selected LBF species based on morphological differences and on quantitative measurements of the rate of growth of each whorl, which is species specific (Racey 1995). We also compare the newly proposed LBF biostratigraphy of the Paleogene rocks of Pakistan with those from other areas Indo-Pacific (Govindon 2003; Mukhopadhyay 2003,2005; and Renema 2002, Matsumaru & Sarma, 2010), Middle East (Bellen et al. 1959; Rahaghi 1980; Kalantari 1981; White 1994; Racey 1994, 1995; and Karim and Baziany 2007) and Europe (Schaub 1981; Sierra-Kiel et al.1998). We use the proposed LBF biostratigraphy of the two basins to investigate the timing of the disappearance of Tethys seaway in the Pakistan area as a result of India-Asia collision.

The present study is based on a detailed stratigraphic logging and a high-resolution LBF analysis of the Paleogene rock units exposed in several key stratigraphic sections (Figs. 2a-b). Systematic rock sampling has been carried out by collecting rock samples with variable intervals (ranges from 10cm to 26m in key stratigraphic sections) in the two basins (Table 2). In the Kohat Basin, we collected samples from the Patala, Panoba, Sheikhan and Kohat Formations, which form part of the north-eastern Sheikhan Nala, Panoba Nala and Tarkhobi Nala Sections and the south-western Bahadur Khel Salt Tunnel Section (Fig. 2a). In the Potwar Basin, we collected samples from Lockhart, Patala, Nammal, Sakessar and Chorgali Formations, which form part of the Gharibwal Cement Factory and Sikki Village Sections in the Eastern Salt Range, Ziarat Thatti Sharif Section in the Western Salt Range, Nammal Gorge Section in the Central Salt Range, Kalabagh Hills and Chichali Nala Section in the Trans Indus Ranges (Fig 2b). About 500 thin sections of rock samples were prepared to study the LBF. In addition, oriented thin sections of individual foraminiferal tests of nummulitids (Nummulites/Assilina) were also used for further identification. The taxonomy of

recorded species is based on a review of the available literature with a focus of faunas from the Indian subcontinent (Nuttal 1926; Davies and Pinfold 1937; Gill 1953; Nagappa 1959; Pascoe 1963; Sarkar

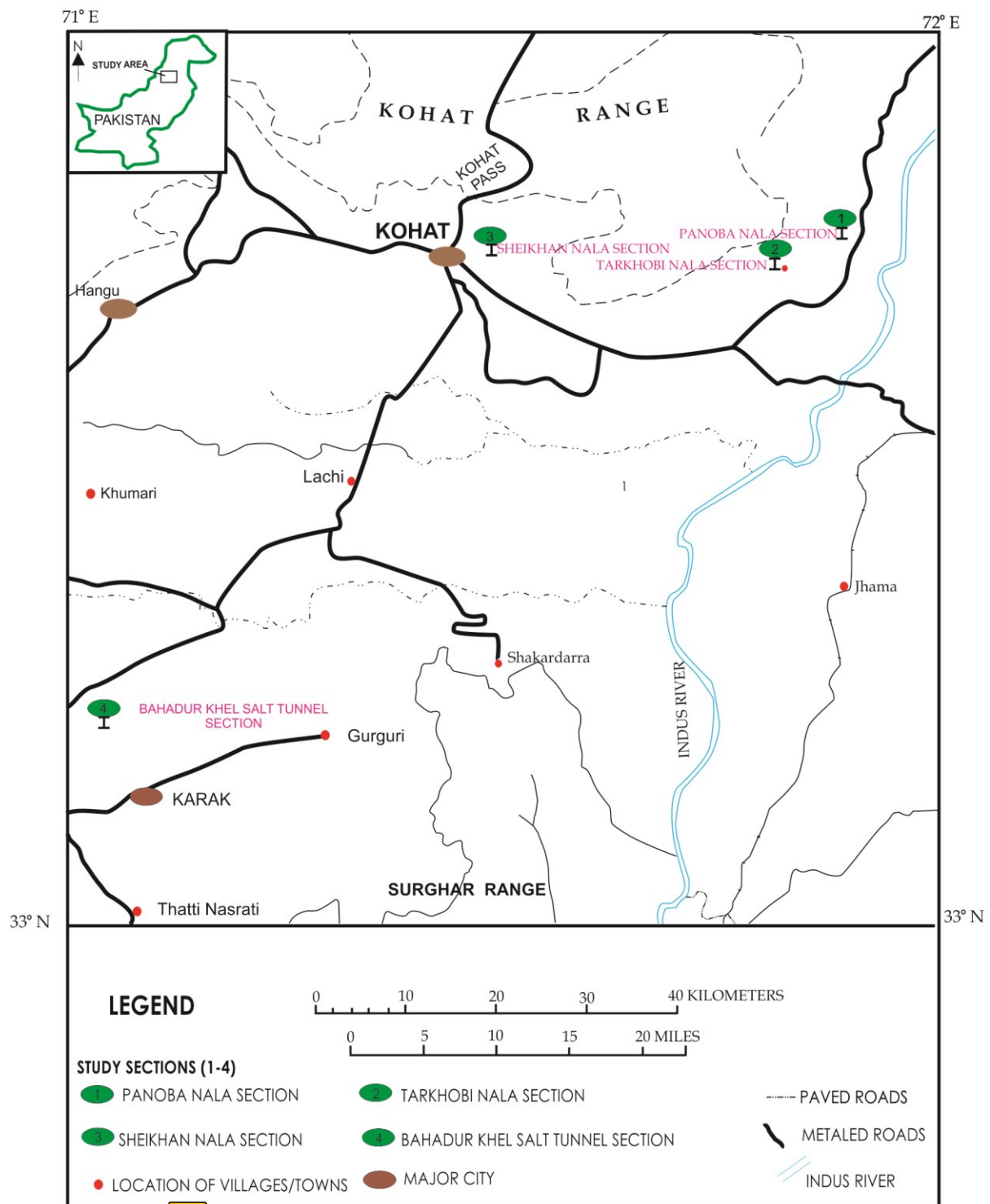


Fig 2a. Accessibility map of the studied sections in Kohat Basin, northwest Pakistan.

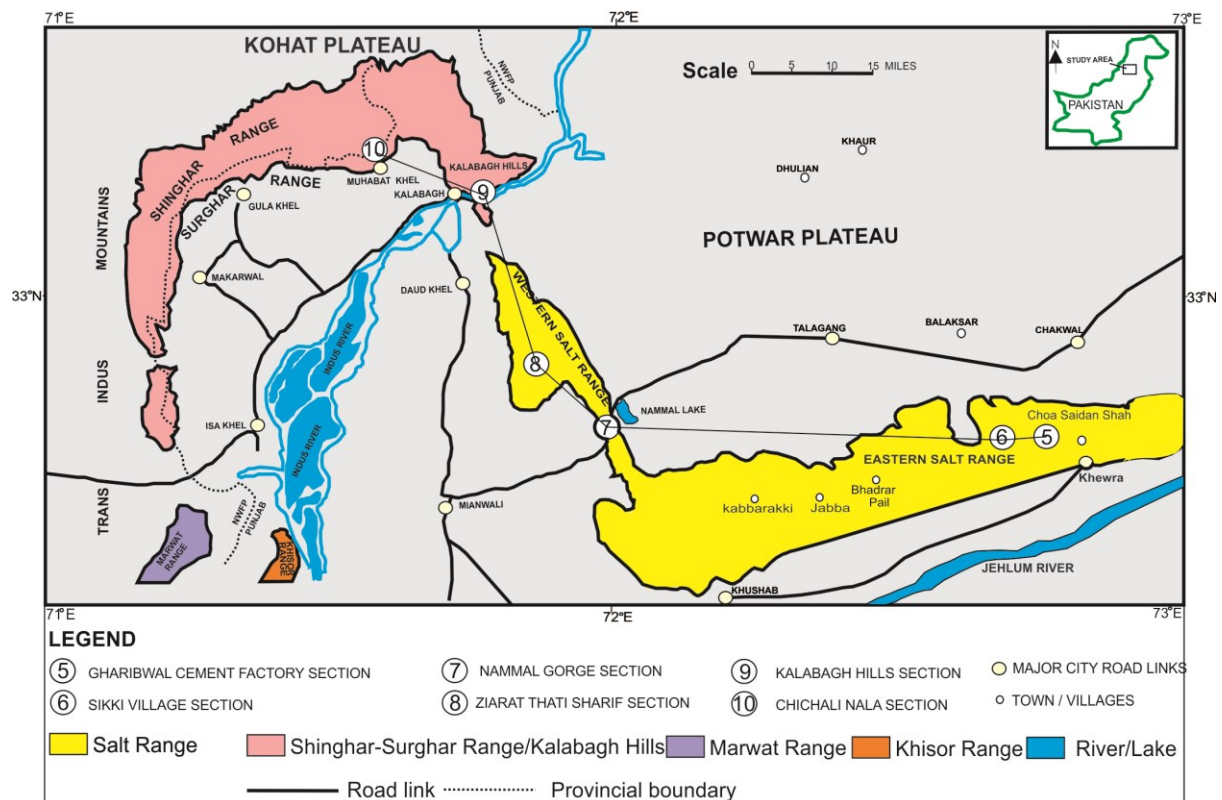


Fig 2b. Accession map of the studied sections in the Potwar Basin and the Trans Indus Ranges (TIR), northwest Pakistan.

	Stratigraphic Sections	Sampling rate	Biostratigraphic samples
KOHAT BASIN	Panoba Nala Section	Variable (from 1-15m)	98
	Tarkhobi Nala Section	Variable (from 1-12m)	53
	Sheikhan Nala Section	Variable (from 1-13m)	131
	Bahadur Khel Salt Tunnel Section	Variable (from 2-13m)	23
			Total= 305
POTWAR BASIN	Gharibwal Cement Factory Sectin	Variable (from 1-2m)	32
	Sikki Village Sectin	Variable (from 1-1.2m)	34
	Nammal Gorge Section	Variable (from 10cm-26m)	112
	Ziarat Thatti Sharif Section	Variable (from 5-10m)	33
TIR	Kalabagh Hills Section	Variable (from 5m-10m)	37
	Chichali Nala Section	Variable (from 10cm-23m)	88
			Total= 336

Table 2: This table shows detail of samples, the range of the rate of rock sampling in key stratigraphic sections of the study area.

1968; Raju et al. 1970, Singh et al. 1970, Sahni and Kumar 1974; Samanta 1965, 1968, 1981; Murty 1983; Jauhri 2006, Jauhri and Agarwal 2001; Mukhopadhyay 2003,2005; Sameeni et al. 1998, 2009; Afzal 2009,2011, and Ahmad et al. 2014), Indo-Pacific region (Verbeek and Fennema 1896; Doornink 1932; Crotty and Engelhardt 1993; Wilson 1995; and Renema 2002), Mediterranean region (Schaub 1981; Serra-Kiel et al.1998) and Tertiary rocks of Middle East (Bellen et al. 1959; Rahaghi 1980; Kalantari 1981; White 1994; Racey 1994, 1995; and Karim and Baziany 2007).

In this study, biometric features including alar prolongation, coarseness of the marginal cord, overlap of spiral sheets, type of coiling (evolute/involute), opening of the spire, number of whorls, chambers (height, shape and numbers) and septal filaments as shown in Fig. 3 are taken into consideration for the identification of species of Nummulites and Assilina, following Racey (1995).

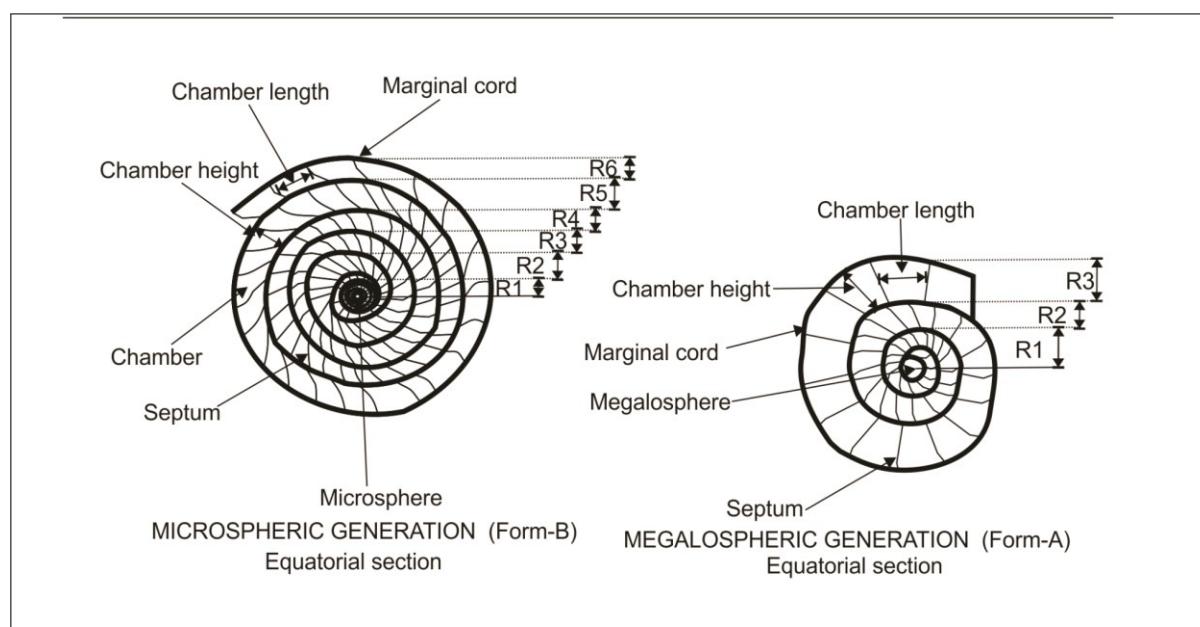


Fig 3. The figure shows morphological features (septum, chambers, marginal cord, micro- and macrospheres) and measurement procedure of the whorl radius in microspheric (Form-B) and megalospheric tests (Form-A) in the Nummulites and Assilina.

BIOMETRIC ANALYSIS OF NUMMULITID FAUNA

In this study the recorded LBF include *Miscellanea miscella* (Plate 1, Fig 1; Plate 3, Fig 1), *Ranikothalia sindensis* (Plate 1, Fig 2), *Discocyliina ranikotensis* (Plate 1, Fig 3, Plate 2, Fig 2; Plate 4, Fig 3), *Lockhartia haimie* (Plate 1, Fig 4; Plate 4, Fig 5), *Assilina dandotica* (Plate 1, Fig 5; Plate 3,

Figs 2-3), *Alveolina globula* (Plate 1, Fig 6; Plate 3, Fig 21), *Nummulites globulus* (Plate 1, Figs 7-8; Plate 3, Figs 15-18), *Nummulites atacicus* (Plate 1, Fig 7; Plate 3, Figs 11-14), *Nummulites pinfoldi* (Plate 2, Fig 1; Plate 4, Figs 7-10), *Assilina spinosa* (Plate 2, Fig 2; Plate 4, Figs 15-18), *Alveolina pasticillata* (Plate 2, Fig 3; Plate 3, Fig 22), *Orbitlites complanatus* (Plate 2, Fig 4), *Assilina exponens* (Plate 2, Fig 5; Plate 3, Figs 29-32), *Assilina laminosa* (Plate 2, Fig 5; Plate 4, Figs 23-25), *Nummulites beaumonti* (Plate 2, Fig 6; Plate 3, Figs 25-28), *Assilina papillata* (Plate 2, Fig 7; Plate 4, Figs 19-22), *Assilina cancellata* (Plate 2, Fig 8; Plate 3, Figs 33-36), *Assilina granulosa* (Plate 3, Figs 4-7), *Assilina pustulosa* (Plate 3, Figs 8-10), *Alveolina vredenburgi (cucumiformis)* (Plate 3, Figs 19-20), *Alveolina elliptica* (Plate 3, Figs 23-24), *Ranikothalia sindensis* (Plate 4, Fig 1), *Operculina* sp. (Plate 4, Fig 2); *Ranikothalia sahni* (Plate 4, Fig 4), *Lockhartia conica* (Plate 4, Fig 6), *Assilina daviesi* (Plate 4, Figs 11-15), *Assilina sutri* (Plate 4, Figs 27-28), and *Nummulites acutus* (Plate 4, Figs 29-32).

It is difficult to define the generic limits in *Nummulites* because of parallel development along several lines (Nagappa 1959; Blondeau 1972). Cole (1964) takes the extreme position in the Treatise and lumps together most of the previously recognized genera into *Nummulites* including *Assilina*, *Operculina*, *Operculinella*, *Operculinoides* and *Ranikothalia*. Höttinger (1977) bases a generic determination on the stolon and canal system and claims that the traditional description of the *Nummulites*, which emphasizes the nature of coiling and presence or absence of secondary septa, should be abandoned. However, Haynes (1981) suggests that a composite approach combining the traditional criteria and evidence of fine structures can help in discrimination of *Nummulites* genera. The usefulness of species of *Nummulites* in the stratigraphic analysis and correlation of the lower Tertiary of the Indo-Pacific region is widely known, but in many of these species identifications are difficult and intra-specific variations have not been investigated (Sen Gupta 1965).

During this study we have found that different *Nummulites* and *Assilina* species show variability in the opening of the spire and the number and radius of successive whorls. For selected index species the number and radius of each whorl, and the number of septa are recorded. Coiling graphs have been drawn to show the rate of opening of spire in all recorded nummulitid species (Text Fig 1A-E). We used the procedure for measurement of the radius in each whorl (Fig 3) as described by Racey (1995)

and Renema (2002). These coiling graphs provide an additional basis for species level differentiation, and are particularly helpful in cases where taxa of Nummulites and Assilina are morphologically similar (Text Fig 1 A-F).

Taxonomy of Nummulitids

The diagnostic morphology of selected index species and reference to the illustrations are given (Plates 1-4). Under the heading, "Diagnosis" diagnostic morphology is elaborated, "Equatorial Section" describes three characters "Whorl", "Radius" and "Chambers" where found are noted. Whorl refers to the whorl number; radius measures the distance (in mm) between the whorl periphery and initial chamber and chambers denotes the number of chambers per whorl. In remarks we differentiate morphologically similar species and discuss the variation in the coiling graphs of selected species (Text Figs. 1 A-E). All studied rock samples/LBF and their representative thin sections are available in the repository at the Museum of Department of Geology, University of Peshawar, Pakistan.

Nummulites *atacticus* Leymerie, 1846

Text Fig 1A-B, Plate 1, Fig 7, Plate 3, Figs, 11-14

Material: (Marls sample 300 grams, 34 specimens, both Form-B and A).

Form-B

Diagnosis

The test shape is lenticular. In equatorial section, a regularly opening spire is present. The initial five whorls are tightly coiled and later ones are loosely coiled (Text Fig 1A), numerous chambers are present which are rectangular and higher than long but in the later whorls chambers are longer than high. Septa are straight to gently incline towards the periphery (Plate 3, Fig 12). A thin marginal cord is present. In axial section, a polar pustule is common in young specimens, which are sometimes buried in adults (Plate 1, Fig 7; Plate 3, Fig 11).

Equatorial Section (Plate 3, Fig 12)

Whorl	1	2	3	4	5	6	7	8
Radius	0.08	0.18	0.44	0.72	1.20	1.56	2.40	3.68
Chambers	6	14	18	2	24	30	38	48

Form-A

Diagnosis

The spire is regularly opening with a straight to inclined septa (Text Fig 1B). Chambers are rectangular and are longer than high. The marginal cord is thin and uniform. Proloculus size of the figured specimen is 0.38mm (Plate 3, Fig 13). In axial section, a polar pustule is common (Plate 3, Fig 14).

Equatorial Section (Plate 3, Fig 13)

Whorl	1	2	3	4	5
Radius (mm)	0.58	0.92	1.44	2.10	2.30
Chambers	8	16	18	22	30

Proloculus size 0.40-0.76mm in diameter

Remarks: In Pakistan *N. atacicus* (in both Forms B and A), early whorls are tight in the spire and later ones are loosely coiled (Text Figs 1A and 1B), When the illustrations of *N. atacicus* (Schaub 1981, pl. figs. 15-30) are compared with this study; the similar morphological features are noted. These features are the non-uniform marginal cord thickness, rapidly opening spire but having early whorls tightly coiled and the dominance of higher than long chambers. Straight to slightly twisted septa are also common in this comparison. The comparison of Form-A with Schaub (1981, pl. 25, figs 10-12 and 41-50) revealed the common presence of 4 whorls, non-uniform marginal cord and straight to slightly curved back septa.

Nummulites *globulus* Leymerie 1846

Text Figs 1 A-B, Plate 1, Figs 7-8, Plate 3, Figs 16-19

Material: (Marls sample 400 grams, 44 specimens, both Form-B and A)

Form-B

Diagnosis

The test is small and biconical. The spire is tight and compact in early five whorls, then regularly opening in later whorls (Text Fig 1A). Septa are straight in early whorls and in later whorls become inclined and sometimes curved back towards the periphery. Chambers are higher than long (Plate 3, Fig 15). In axial section, scattered pillars are seen (Plate 3, Fig 23).

Equatorial Section (Plate 3, Fig 15)

Whorl	1	2	3	4	5	6
Radius (mm)	0.08	0.14	0.26	0.43	0.62	0.91
Chambers	12	16	22	24	26	28
Whorl	7	8	9			
Radius (mm)	1.15	1.46	1.67			
Chambers	35	48	53			

Form-A**Diagnosis**

A rapidly opening spire characterizes this species (Text Fig 1B). The septa are straight to inclined and higher than long (Plate 1, Fig 12). The marginal cord is non uniform. In axial section a thick polar pillars and a large proloculus is present (Plate 3, Fig 18).

Equatorial Section (Plate 3, Fig 17)

Whorl	1	2	3	4	5
Radius (mm)	0.42	0.63	0.86	1.04	1.24
Chambers	10	18	20	29	37

Proloculus size 0.60-1.10 mm in diameter

Remarks: *N. globulus* Leymerie is the Form-B of *N. mamilla* Fichtel & Moll. The comparison of figured topotype material of *N. globulus* (Schaub 1981, pl. 40, figs 1-60) revealed the commonly found morphological features which are the presence of 7-8 whorls with initial whorls tightly coiled and later whorls loosely coiled, isometric chambers with straight to curved back septa are noted (Schaub 1981, pl. 40, figs 42-45). The central pillars within the axial section are also common (Schaub 1981, pl. 40, figs 50-51). The European specimens of the Form-A (Schaub 1981, pl. 40, figs 26-29) have similarity with this study in having up to 4 whorls in a regularly opening spire, central pillars and curved back septa.

Nummulites beaumonti d' Archiac & Haime 1853

Text Figs 1 A-B, Plate 2, Fig 6; Plate 3, Figs 25-28

Material: (400 grams Nummulitic shales; 60 specimens, both Form-B and A)

Form-B

Diagnosis

In equatorial section, the spire is regularly opening (Text Fig 1A). Septa are mostly inclined, numerous chambers (4-66) are present which are mostly higher than long. The marginal cord is uniform (Plate 3, Fig 25). In axial section, the pillars are commonly scattered (Plate 2, Fig 6; Plate 3, Fig 26). The diameter of figured specimen is 6.36 mm. The average thicknesses of 5 studied specimens is 3.8 mm, maximum observed thickness is 4.5 mm and average ratio of the diameter to thickness is 1.8 to 1.

Equatorial Section (Plate 3, Fig 25)

Whorl	1	2	3	4	5	6
Radius (mm)	0.12	0.24	0.40	0.69	0.80	0.85
Chambers	04	20	27	29	33	38
Whorl	7	8	9	10	11	12
Radius (mm)	1.20	1.79	2.18	2.54	2.88	3.18
Chambers	20	48	53	55	60	66

Form-A

Diagnosis

In the equatorial section, the spire displays regular opening, having six whorls (Text Fig 1B, Plate 3, Fig 27). Chambers are higher than long but longer than high chambers are also found in the later whorls. The septa are mostly straight, but inclined in early and last whorls. The marginal cord thickness is not uniform. In axial section, pillars are commonly scattered (Plate 3, Fig 28). The diameter of the proloculus in the figured specimen is 0.24 mm.

Equatorial Section (Plate 3, Fig 27)

Whorl	1	2	3	4	5	6
Radius (mm)	0.30	0.57	0.78	1.03	1.13	1.24
Chambers	13	16	21	24	33	40

Proloculus size 0.12-0.24mm in diameter

Remarks: The specimens of *N. beaumonti* from the Cambay Basin, India are characterized by inflated lenticular test, acute peripheral margin, radial septal filaments slightly curving at the polar

part, tight spire, chambers of mature whorls having length nearly equal to height, uniform whorl wall containing a few spiral canals including a thick proximal canal, fairly wide alar prolongations, thin marginal cord, buried polar pillars, moderately high foramina and moderately large bilocular proloculus (diameter 0.275 mm - 0.475 mm) having protoconch larger than the deuterioconch (Mukhopadhyay 2005, Plate 2, figs 1-14), Some of the forms from Kutch (pl. 2, fig.7, and pl. 5, fig. 10) have characters, both of *N. discorbinus* and *N. beaumonti*. In the study area the *N. beaumonti* is having a regularly opening spire, but the eighth whorl shows tightness of the spire and a partial tripartite nature, as the later whorls again show regular opening of the spire (Text Figs. 1 A-B). The commonly noted features between the Indian specimens and this study are the presence of radial septal filaments, fairly wide alar prolongations, thin marginal cord and buried polar pillars while dissimilar chambers in the last few whorls are seen (Mukhopadhyay 2005).

Nummulites acutus Sowerby, 1840

Text Figs 1 A-B, Plate 4, Figs 29-32

Material: (Nummulitic shales sample 600 grams, 19 specimens, both Form-B and A)

Form-B

Diagnosis

In equatorial section, the spire is gradually opening (Text Fig 1A, Plate 4, Fig 29). Granules are commonly present along the meandrine septal filaments and generally throughout the spire. Chambers are rectangular, occasionally isometric and are longer than high. The septa are gently curved in early whorls and curved back in later whorls. The marginal cord is not uniform; while scattered pillars are commonly present (Plate 4, Fig 30). The average thickness to diameter ratio of the 10 measured specimens varies from 2.5 mm to 1.2 mm.

Equatorial Section (Plate 4, Fig 29)

Whorl	1	2	3	4	5	6	7	8	9	10
Radius (mm)	0.24	0.40	0.80	1.14	1.55	1.85	2.16	2.49	2.64	2.82
Chambers	17	22	24	26	34	38	44	48	50	56

Form-A

Diagnosis

In equatorial section, the spire is gradually opening (Text Fig 1B). The septa are inclined. Chambers are rectangular and longer than high (Plate 4, Fig 31). A non-uniform marginal cord is seen that equals $2/4^{\text{th}}$ - $3/4^{\text{th}}$ of the chamber height. In axial section a large proloculus and scattered pillars are present (Plate 4, Fig 32).

Equatorial Section (Plate 4, Fig 31)

Whorl	1	2	3	4
Radius (mm)	0.47	0.68	0.86	1.01
Chambers	10	20	30	36

Proloculus size 0.44-0.64mm in diameter

Genus *Assilina* d' Orbigny

Type species: *Nummulites spira* Roissy

The genus *Assilina* embraces all those forms which are morphologically like *Nummulites* but characterized by evolute coiling, whereas in *Nummulites* the coiling is involute. Cole (1960) stated that individual species may grade from involute to evolute, and thus he identified *Paleocamerinoides* Cole (genotype *Nummulites exponens* Sowerby) as a junior synonym of *Nummulites*. In the past the megalospheric and microspheric forms of *Assilina* were designated by two different names. As these names are in common use, therefore, they are retained here with A and B forms being identified in the diagnosis. The stratigraphic range of *Assilina* is Paleocene to Eocene.

Assilina dandotica Davies & Pinfold, 1937

Text Fig 1C, Plate 1, Fig 5, Plate 3, Figs 2-3

Material: (300 grams argillaceous limestone, 09 specimens only Form B)

Form-B

Diagnosis

The test is discoidal with a sharp periphery; in equatorial section the spire is tight, regularly opening (Text Fig. 1C), granules are common, septa straight to slightly curved in later whorls, chambers are rectangular, twice higher than long (Plate 3, Fig 2). In axial section, the spiral sheet completely embraces the succeeding whorls (Plate 3; Figs 3).

Equatorial Section (Plate 3, Fig 2)

Whorl	1	2	3	4
Radius	0.27	0.56	0.94	1.39
Chambers	7	14	20	25

Remarks: The comparison of *A. dandotica* from Pakistan with the Schaub specimens (1981, pl. 84, figs 5, 7, 16) demonstrate common features that include 4 whorls in a regularly opening spire and straight to slightly twisted septa in later whorls. However the difference in the chamber shape is noted. The Schaub (1981) specimens characterize dominance of the isometric chambers, but in present study rectangular chambers are dominant in the Pakistani specimens. The axial sections of *A. dandotica* in both areas are quite similar.

Assilina exponens Sowerby, 1840

Text Figs 1 D-E, Plate 2, Fig 5; Plate 3, Figs 29-32

Material: (600 grams Nummulitic shales; 30 specimens both Form-B and A)

Form-B

Diagnosis

The spire is regular, but compact with some irregularities due to doubling in the middle to outer whorls (Text Fig. 1E). Chambers are higher than long and slightly inclined (Plate 3, Fig 29). In axial section polar pillars are prominent (Plate 3; Fig 30).

Equatorial Section (Plate 3, Fig 29)

Whorl	1	2	3	4	5	6
Radius (mm)	0.1	0.8	0.47	0.66	1.08	1.33

Chambers	4	12	17	20	22	24
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Whorl	7	8	9	10	11	12
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Radius (mm)	1.63	1.83	2.47	3.39	4.36	5.07
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Chambers	29	31	36	48	52	62
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Form-A

Diagnosis

The test is evolute, lenticular to flatten-lenticular in shape. It has a slightly swollen polar region and often shows a small polar depression. Ornaments are similar to Form-B (Plate 3, Fig 31). The spire is regular (Text Fig. 1F). In axial section the granules are distributed throughout the test and scattered, buried pillars are commonly present (Plate 3; Fig 32).

Equatorial Section (Plate 3, Fig 31)

Whorl	1	2	3	4	5	6
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Radius	0.96	1.60	2.14	2.94	3.90	4.30
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Chambers	9	20	26	35	32	43
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Proloculus size 0.54-0.80mm in diameter

Remarks: The morphological comparison of the Pakistani specimens with the European specimens of *A. exponens* (Schaub 1981, pl. 92 figs 1-20) shows that Form-B in both regions have a regularly opening spire with tight early and loose later whorls, straight to slightly curved forward septa, external central depression with heavy granulation is common. However the European specimens are larger in size.

Assilina cancellata Nuttall, 1926

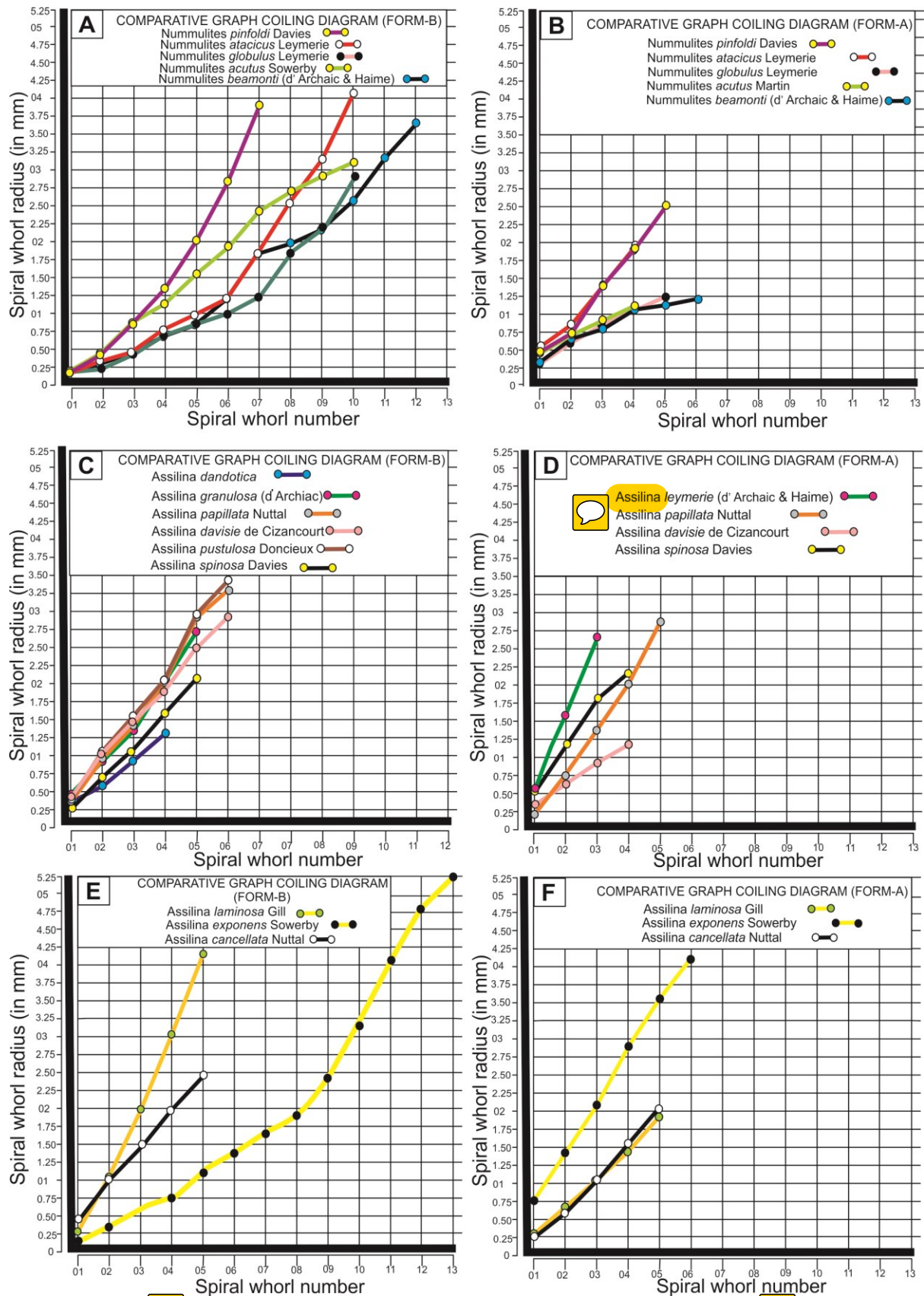
Text Figs 1 E-F; Plate 3; Figs 33-35

Material: (600 grams Nummulitic shale, 18 specimens, both Form-B and A)

Form-B

Diagnosis:

The test is flat, lenticular, with sharp periphery, non-ornamented smooth exterior surface. The septa are straight in shape. Chambers are higher than long (Plate 3, Fig 33). The spire is gradually opening (Text Fig. 1E, Plate 3; Fig 33). The marginal cord is uniformly thick and granules are present in the center.



Text Figure 1. The coiling graph plots of different species of **Nummulites** (A-B) and **Assilina** (C-F) recorded in the study area.

Equatorial Section (Plate 3. Fig 33)

Whorl	1	2	3	4	5
Radius (mm)	0.43	0.99	1.42	1.89	2.4
Chambers	5	19	25	32	38

Remarks: It is the microspheric Form-B of the *A. subcancellata* Nuttal

Form-A**Diagnosis:**

The spire is tight, but in later whorls becoming loosely coiled (Text Fig. 1F). Chambers are rectangular, higher than long separated by straight to gently incline in later whorls (Plate 3; Fig. 35).

The axial section shows the same morphological features as that of Form-B but it is smaller in size (Plate 3; Fig. 36).

Equatorial Section (Plate 3, Fig 35)

Whorl	1	2	3	4	5
Radius (mm)	0.24	0.51	1.05	1.52	2.1
Chambers	5	8	16	24	30

BIOSTRATIGRAPHY

The biostratigraphic range distribution of selected index nummulitid species and associated larger foraminifera (Plates 1-4) are used to establish biozonal boundaries in the Paleogene successions of the study area (Fig 4). These zonal boundaries divide the Paleogene succession of the Kohat and Potwar basins into six and three larger Benthic Foraminiferal Zone (BFZ 1-6 Zones) respectively. The BFZ Zones of local nature are correlated with earlier local biozonation in the Kohat Basin (Vredenburg 1909, Gee 1944, Nagappa 1959), Potwar Basin (Weiss 1988,1993, Afzal 1997, Sameeni 2009, Afzal 200,2011), regional biozonation and species in Indian Basins (Govindon, 2003; Matsumaru & Sarma, 2010), and the Western Tethys LBF standard Zones (Höttinger 1960; Schaub 1981; and Serra-Kiel et al. 1998). The absolute chronologic calibration of the BFZ 1-6 Zones are based on the magnetostratigraphy as presented in the Geological Time Scale (Berggren et al. 1995). The descriptions of the BFZs are as follows.

BFZ 1 Zone

The FO of *Miscellanea miscella*, *Lockhartia haimeii* and *Ranikothalia sindensis* defines this Zone (Fig 4). The associated LBF include, *L. conica*, *L. huntii*, *L. newboldi*, *Operculina salsa*, *O. subsalsa*, *Discocyclus ranikotensis*, and *N. pinfoldi*.

The BFZ 1 Zone is correlated with the Ranikot Stage of Sind area (Vredenburg 1909) and Khairabad Limestone of Punjab Salt Range (Gee 1944). In the Jaintia Hills, Meghalaya, NE India Assemblage 2 of LBF (*M. miscella*, *M. primitiva*, *Ranikothalia nuttalli* and *Lockhartia haimeii*) within the Lakadong Limestone (Matsumaru & Sarma, 2010) is well correlated with the BFZ 1 Zone. The *M. miscella* was also documented in the LFA 1 Zone as Tertiary a1 Zone of Indian Basins by Govindon, 2003, representing the upper Paleocene (Thanetian) of Letter Stages. Based on the FO of *M. miscella* it can tentatively be correlated with the Shallow benthic Zone" (SBZ 4) by Serra-Kiel et al. (1998) (Fig 4).

The thickness of BFZ 1 Zone is ranging from 11m-212m in the Kohat Basin in Shikhan and Tarkhobi Nala Sections (Fig 5) while its thickness is ranging between 21m-143m in the Potwar Basin in Sikki Village and Kalabagh Hills Section (Fig 6).

Geological age: Late Paleocene (Thanetian).

BFZ 2 Zone

The stratigraphic ranges of *Assilina dandotica*, *A. pustulosa*, *Alveolina globula* and *Al. pasticillata* define this Zone (Fig 4). The associated LBF include *A. spinosa*, *N. pinfoldi*, *Operculina* sp, *Al. vredenburghii* (*cucumiformis*), and *L. conica*. The BFZ 2 Zone is partially correlated with the lower Laki Limestone of Laki Stage of Sind area in Pakistan (Vredenburg 1909; Nagappa 1959). It partially correlates with the LBF Assemblage 2 recorded in the Jaintia Hills, Meghalaya, NE India (Matsumaru & Sarma, 2010) and partially with the LFA 1-2 Zone of Indian Basins (Govindon, 2003). Based on the biostratigraphic occurrence of *A. dandotica*, *A. pustulosa*, *Al. vredenburghii* (*cucumiformis*) and *Al. globula*, the BFZ 2 Zone is partially correlated with the Shallow benthic Zone; SBZ 5-7 Zone (Serra-Kiel et al. 1998), representing Early Eocene (Lower Illeridian 1-Middle Illeridian 1) (Fig 4). In the Kohat Basin, the thickness of BFZ 2 Zone is ranging from 9m-30m in the

Sheikhan and Tarkhobi Nala Sections (Fig 5), while it is 10m-180m thick in the Potwar Basin and adjacent TIR in the Nammal Gorge and Kalabagh Hills Section respectively (Fig 6).

BFZ 3 Zone

The FO of *Nummulites atacicus*, *Nummulites globulus* and FO of *Orbitolites complanatus* defines this Zone (Fig 4). The associated LBF include *R. sahini*, *N. pinfoldi*, *A. spinosa*, *A. laminosa*, *Al. elliptica*, *L. conica* and *Operculina* sp. The BFZ 3 Zone is correlated with the fauna of Laki Stage in Punjab Salt Range, Pakistan (Gee 1944; Nagappa 1959). The BFZ 3 Zone can also be correlated with the LBF Assemblages 3-1 and 3-2 recorded in the upper part of the Umlatdoh Limestone in the Jaintia Hills, Meghalaya, NE India (Matsumaru & Sarma, 2010). Govindon (2003) also reported *N. atacicus* in his LFA 2 and 3 Zone as Tertiary a2, representing lower Eocene (Ypresian) in Indian Basins. Based on the FO of *N. atacicus* (after Schaub, 1981) and *Orbitolites complanatus*, the BFZ 3 Zone can be correlated with the Shallow benthic Zone; SBZ 8 to 11 (Serra-Kiel et al. 1998).

In the Kohat Basin, the thickness of BFZ 3 Zone is ranging from 22m to 55m in the Sheikhan and Panoba Nala Sections respectively (Fig 5). The BFZ 3 Zone is 12m-315m thick in in the Potwar Basin and TIR, in the Kalabagh and Chahali Nala Sections (Fig 6).

Geological age: Early Eocene (Middle Illeridian 2- Middle Cuisian)

BFZ 4 Zone

The FO of *Assilina exponens* (in Schaub, 1981) defines the base while the FO of *N. beaumonti* marks the top of this Zone. The associated LBF include *N. pinfoldi*, *A. papillata*, *A. laminosa*, *A. spinosa*, and *A. sutri*. The BFZ 4 Zone is correlated with the fauna of Kirthar Stage in Punjab Salt Range, Pakistan (Nagappa 1959). The BFZ 4 Zone partially correlates with the Assemblage 4 (1) in the Jaintia Hills, Meghalaya, NE India (Matsumaru & Sarma, 2010), LFA 4 to 6 (Tertiary a3) in the Indian Basins (Govindon, 2003) and the Shallow benthic Zone; SBZ Zone 14 (Serra-Kiel et al. 1998).

In the Kohat Basin, the BFZ 4 Zone is 32m thick, recorded in the Kohat Formation in the Sheikhan Nala Section (Fig 4). It is not recorded in the Potwar Basin and TIR (Figs 4 & 6).

Geological age: Middle Eocene (Middle Lutetian 1).

BFZ 5 Zone

The FO of *Numulites beaumonti* defines the base while FO of *A. cancellata* marks the top of this Zone. Other associated LBF include *Al. elliptica*, and *N. acutus*. The BFZ 5 Zone is correlated with the fauna of Kirthar Stage in Punjab Salt Range, Pakistan (Nagappa 1959). The BFZ 5 Zone can be

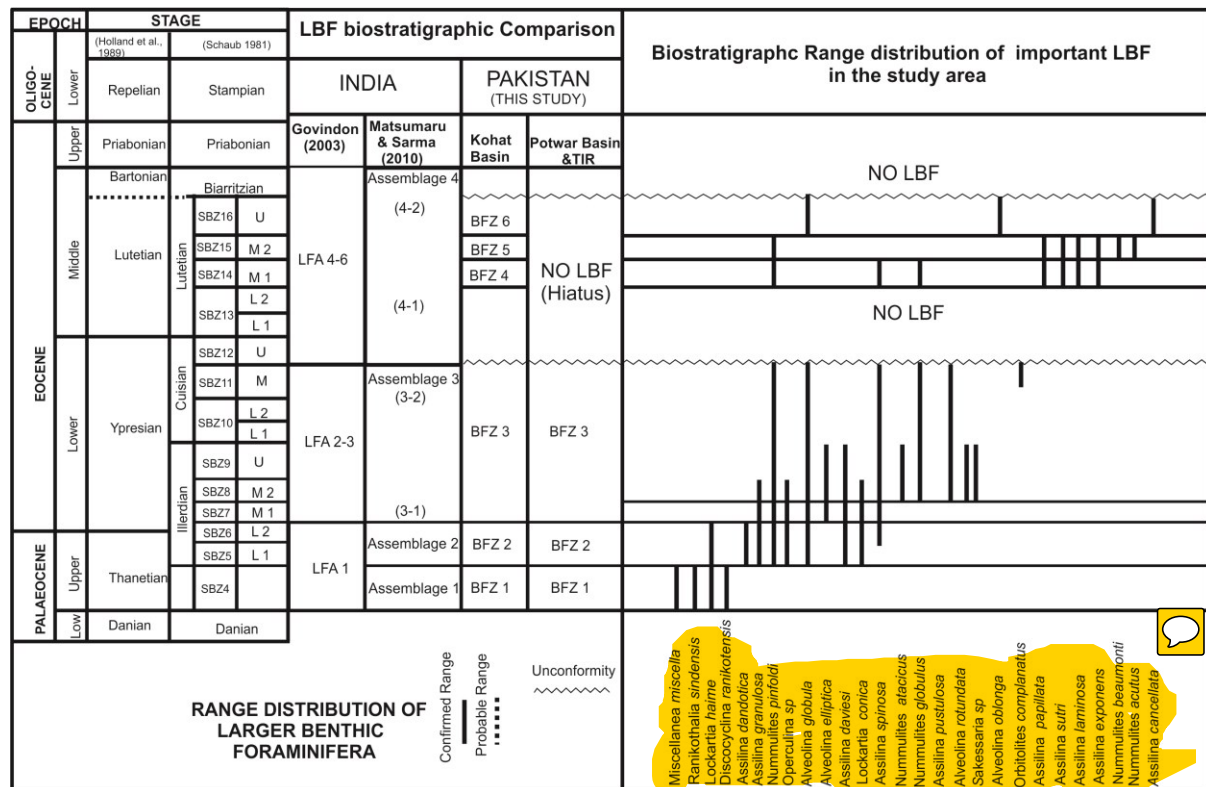


Fig 4. Comparison of larger benthic foraminiferal biostratigraphic zonation (BFZ 1-6 Zones) of the Paleogene rocks of study area with the regional biozonation in Indian Basins (Govindon 2003, Matsumaru & Sarma, 2010) and Western Tethys SBZ Biozone of Serra Kiel et al. (1998).

correlated with the Assemblages 4-1 and 4-2, recorded in middle Prang Limestone, exposed in the Jaintia Hills, Meghalaya, NE India (Matsumaru & Sarma, 2010).

In the Kohat Basin, the BFZ 5 Zone is 9m thick, recorded only in the Kohat Formation, exposed in the Sheikhhan Nala Section (Fig 4). It is not recorded in the Potwar Basin and TIR (Figs 4 & 6).

Geological age: Middle Eocene (Middle Lutetian 2)

BFZ 6 Zone

The stratigraphic range of *Assilina cancellata* (in Schaub, 1981) defines this Zone. The associated LBF include *N. beaumonti*, *N. acutus*, *A. papillata*, *Operculina* sp and *Al. elliptica*. The BFZ 6 Zone is correlated with the fauna of Kirthar Stage in Punjab Salt Range, Pakistan (Nagappa 1959).

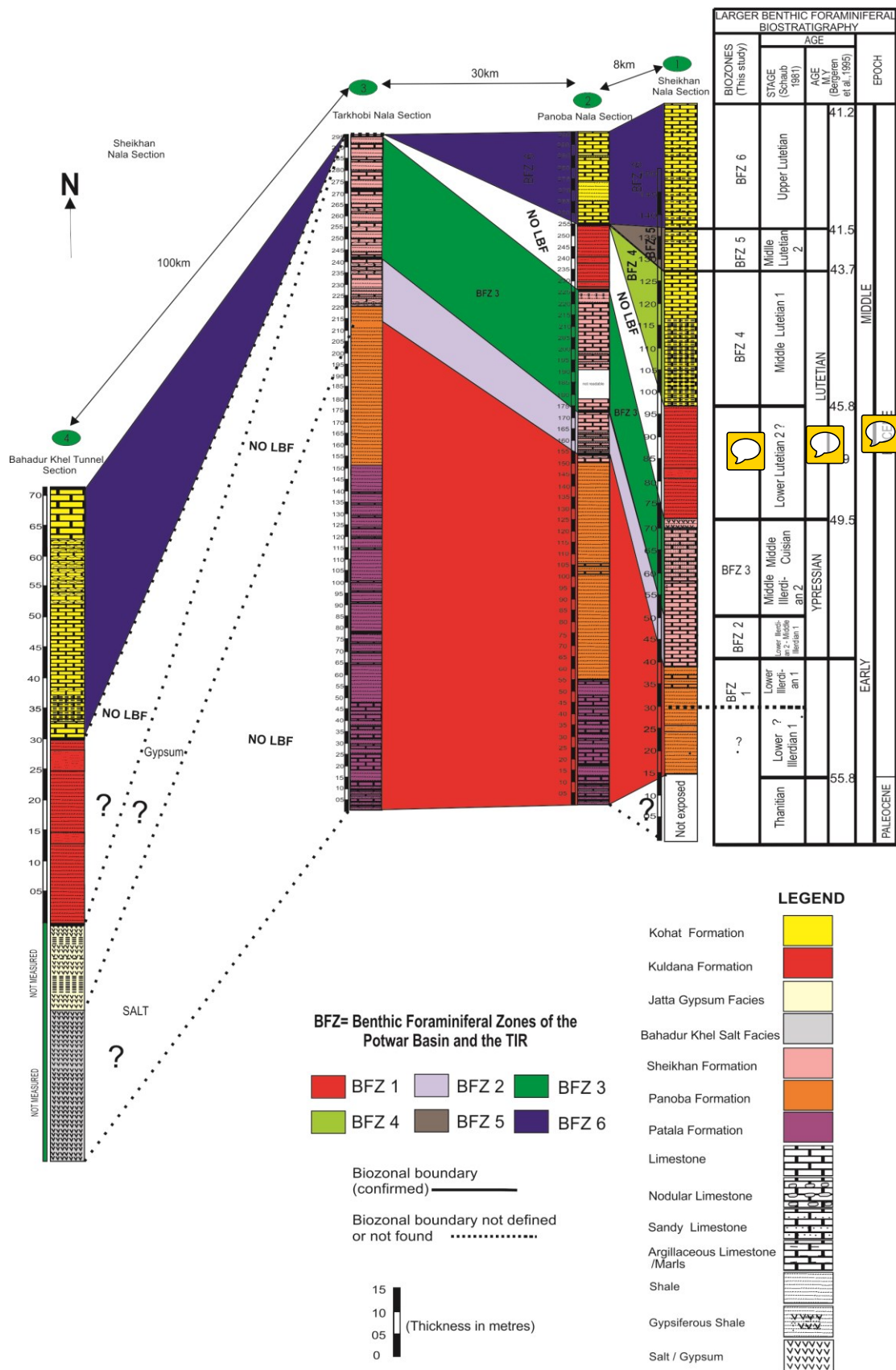


Fig 5. Biostratigraphic correlation of the Paleogene rocks in studied sections of the Kohat Basin.

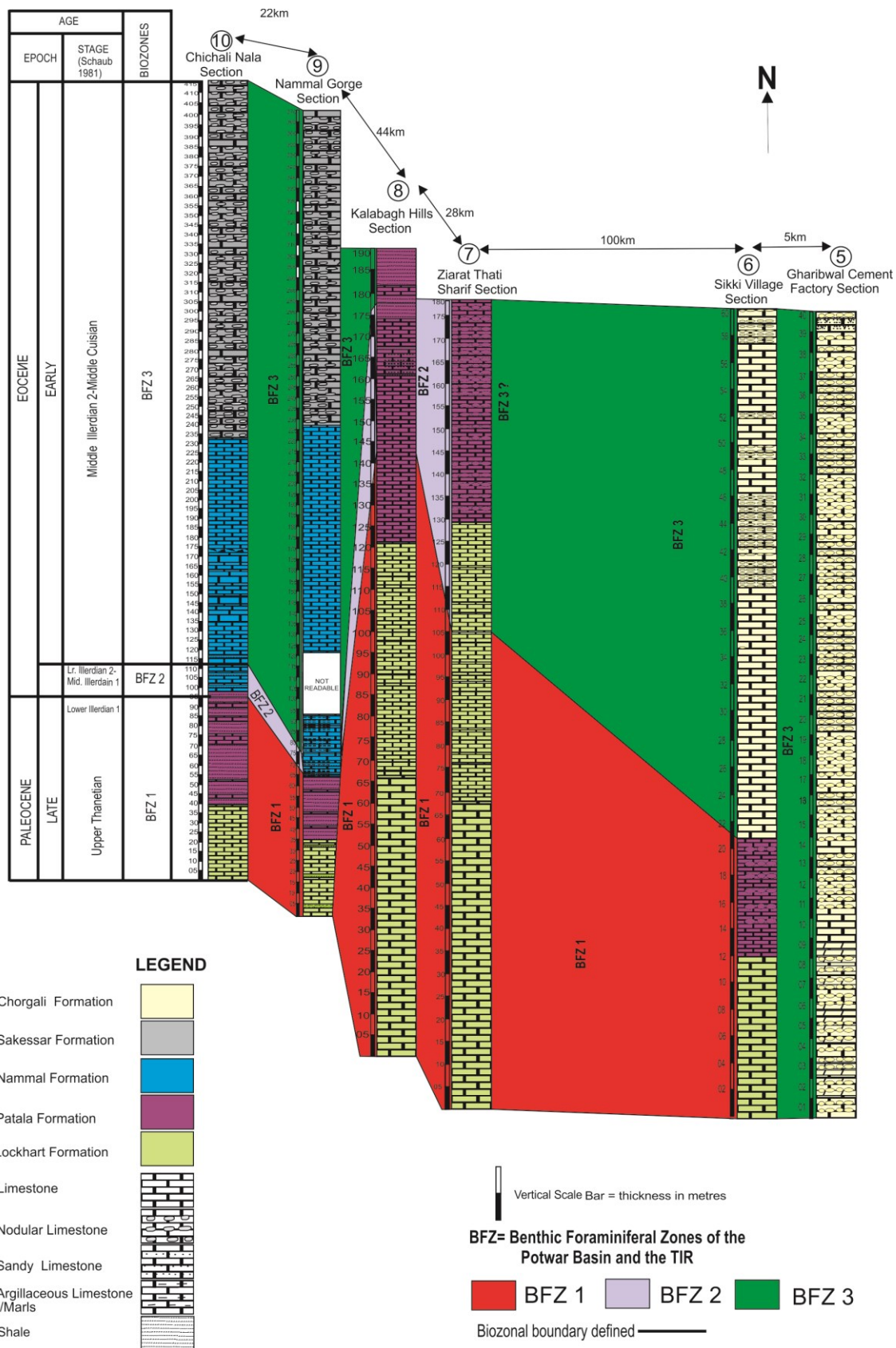


Fig 6. Paleogene biostratigraphic correlation chart of the studied sections in the Potwar Basin and Trans Indus Ranges (TIR).

This Zone can be correlated with the Assemblages 4-1 and 4-2 recorded in the middle Prang Limestone, in NE India (Matsumaru & Sarma, 2010) and LFA 4 to 6 (Tertiary a3) in other Indian Basins (Govindon, 2003). Based on the stratigraphic range of *A. cancellata* in Schaub (1981), the BFZ 6 Zone is equivalent to the *A. gigantea* Zone of Schaub (1981), and it can partially be correlated with the Shallow benthic Zone; SBZ Zone 16 (Serra-Kiel et al. 1998).

In the Kohat Basin, the BFZ 6 Zone is 28m thick in the Sheikan Nala and 40m thick in the Panoba Nala Section (Fig 4). The BFZ 6 Zone is not recorded in the Potwar Basin and TIR.

Geological age: Middle Eocene (Upper Lutetian).

DISCUSSION

Inter-regional biostratigraphic correlation

The LBF are important stratigraphic indicators of Paleogene rocks throughout the Neotethys. Carbonate sequences are correlated based on the occurrences of Nummulites, Assilina and Alveolina in the Indo-Pacific (Vredenburg 1909, Gee 1944, Nagappa 1959, Weiss 1988, 1993, Afzal 1997, Sameeni et al. 1998, 2009; Afzal 2009, 2011, Ahmad et al. 2014), Middle East (Kalantari 1981; Racey 1994, 1995; Rahaghi 1980; White 1994 and Karim and Baziany 2007) and Europe (Höttinger 1960, 1971; Schaub 1966, 1981; and Serra-Kiel et al. 1998). Various authors have created Zones with a global significance based on the LBF (Höttinger 1960; Schaub 1981; and Serra-Kiel 1998). These Zones are very useful to date carbonate strata of Late Paleocene to Oligocene. The LBF Zones have been correlated with the planktonic foraminiferal and coccolithophorid Zone (Cavalier and Pomerol 1986; Harland et al. 1989).

The LBF of the Paleogene sequences of Kohat and Potwar Basins have not been studied in great detail or have not been illustrated as yet (Davies 1940, Vredenburg 1906, Eames 1950 & 1952, Afzal 1997, Roohi and Baqri, 2004, Sameeni et al. 1998, 2004, 2009, Gahzi et al. 2010, Afzal 2008 & 2010; Ahmad et al. 2014). In this paper, we describe the stratigraphic occurrences of selected age diagnostic nummulitid and associated species (Fig. 4). We define the boundaries of the local Zones as much as possible based on FO of species which are known to have chronostratigraphic significance in carbonate sequences from the Indo-Pacific, Middle East, and European areas. We discuss here in

detail the usefulness of the LBF to subdivide the Kohat and Potwar Paleogene sequences, correlation of the boundaries to other areas such Indo-Pacific, Middle East, and Europe, and the implications for dating of these boundaries.

We made a literature review to investigate the global significance of the first and last appearances of selected LBF as a chronostratigraphic marker. The new LBF data from Pakistan are placed in the context of such a biostratigraphic framework for the first time. The new data are plotted together with data from other areas in Fig 7, with the aim to visualise the synchronicity or diachronicity of the first and last occurrences of the selected LBF with the regional biostratigraphic zones in the Eastern part of Tethys in India (Govindon, 2003, Matsumaru and Sarma, 2010), in the European part of the western Tethys Shallow benthic Zone; SBZ Zone (Serra-Kiel et al. 1998) and the Middle East region (Racey, 1995).

The Late Paleocene (Thanetian) sediments are indicated by the co-occurrence of *M. miscella*, *Ranikothalia sindensis* and *D. ranikotensis* in several sections of both the Kohat and Potwar Basins within BFZ 1 Zone (Fig 4). In Tethyan Himalaya of Tibet it has been reported in the SBZ5 slightly later than Western Tethys (Qinghai et al, 2013). In Europe (France), *Miscellanea* sp. was found associated with the *R. bermudezi* and *D. seunesi* indicating Late Paleocene (Thanetian≈SBZ4) age (Tambareau and Villate 1977; Höttinger 1960; Tambareau 1972). These species occurred throughout the Tethys in Late Thanetian (≈SBZ4-5) (Racey 1995; Serra-Kiel et al. 1998,). The disappearance of *M. miscella* and *R. sindensis* coincide with the upper boundary of the Late Paleocene (Thanetian≈SBZ4)(Fig 4). This boundary is further marked by the FO of *A. dandotica* in the Kohat and Potwar Basins. The FO of *A. dandotica* is synchronous in sections from the Indo-Pacific, Middle East (Oman) and Europe (Fig 7). The FO of *A. dandotica* has been recorded from Eastern Neo-Tethys (Pakistan), representing Early Eocene (Lower Illeridian 1≈SBZ5). In the Middle East and Europe, *A. dandotica* represents Early Eocene (Lower Illeridian 1-lower Illeridian 2≈SBZ5-6) (Schaub 1981, White 1994, Racey 1995). From this review, it appears that *A. dandotica* synchronously evolved throughout the Neo-Tethys. We conclude that FO of *A. dandotica* is a global marker for the Late Paleocene (Thanetian≈SBZ4)-Early Eocene (lower Illeridian 1≈SBZ5) Boundary. Furthermore the co-occurrence of *A. pustulosa*, *Al. vredenburgi (cucumiformis)*, *Al. globula* and *Al. pasticillata*

characterizes the Early Eocene (Lower Illerian 1-Middle Illerian 1≈SBZ5-SBZ7) LBF assemblage within the BFZ 2 Zone. The BFZ 2 Zone can be compared with the SRX 2 and SRX 3 Zone of Afzal (1997) and the upper part of the *Lockhartia haime-Dictyokathina simplex* Zone of Weiss (1988, 1993) in the Potwar Basin.

In study area the BFZ 3 Zone is characterized by the simultaneous FO of *N. globulus* and *N. atcicus* and FO of *Orbitolites complanatus* (Fig 4). The BFZ 3 Zone can be compared with the *Assilina leymerie/Nummulites globulus* Zone of Schaub (1981), the SRX 5-7 Zone of Afzal (1997), and the lower part of the *Assilina leymerie-Nummulites fossulata-Discocyclina ranikotensis* Zone -*Assilina spinosa-Flosculina glubosa-Dictyokathina cooki* Zone of Weiss (1988, 1993). The literature review suggests that *N. globulus* was found in the Early Eocene shoal facies of Kurdistan in northeast Iraq (Bellen et al. 1959; Karim and Bazainy, 2007). In the northern Spain and southern France it is representing Early Eocene (Middle Illerian 2) (Höttinger 1960, Tambareau and Villate, 1977; Robador et al. 1991; Schaub 1981). In India, it represents Early Eocene (Middle Illerian 2≈SBZ8)-Middle Eocene (Middle Lutetian 2≈SBZ15) (Jauhri 1997, 2006; Jauhri and Agarwal 2001). It appears synchronously with *N. atcicus* in Europe (Schaub 1981). In the Kohat Basin, however, it has an extended range compared to Europe, because we also found it in the Middle Lutetian 1 (≈SBZ14). Therefore, only the synchronous FO of *N. atcicus* and *N. globulus* are considered excellent global biostratigraphic markers of the Early Eocene (Middle Illerian 1-Middle Illerian 2≈SBZ7-SBZ8) Boundary (Fig 7). The FO of *Orbitolites complanatus* (Serra-Kiel et al 1998) is useful for constraining the age of the sediments (BFZ 3) below the terrestrial Koldana beds (Gingerich, 1977, 2003). The co-occurrence of these species in this interval of only a few meters indicates the Early Eocene (Upper Illerian-Middle Cuisian≈SBZ9-SBZ11) age (Fig 4 & 7). The *O. complanatus* has been reported in Assemblage 3-1 and 4-1, representing Early-Middle Eocene (Middle Cuisian-middle Lutetian 1≈SBZ 11-SBZ15) from the Umladoh Limestone and Prang Limestone, exposed in the Jaintia Hills, Meghalaya, NE India (Matsumaru & Sarma, 2010). It seems that *O. complanatus* has appeared simultaneously in the study area (Middle Cuisian≈SBZ11) and Indian Basins (Govindon 2003, Matsumaru & Sarma 2010). In Tibet (Willems and Zhang 1993) also found *O. complanatus* in

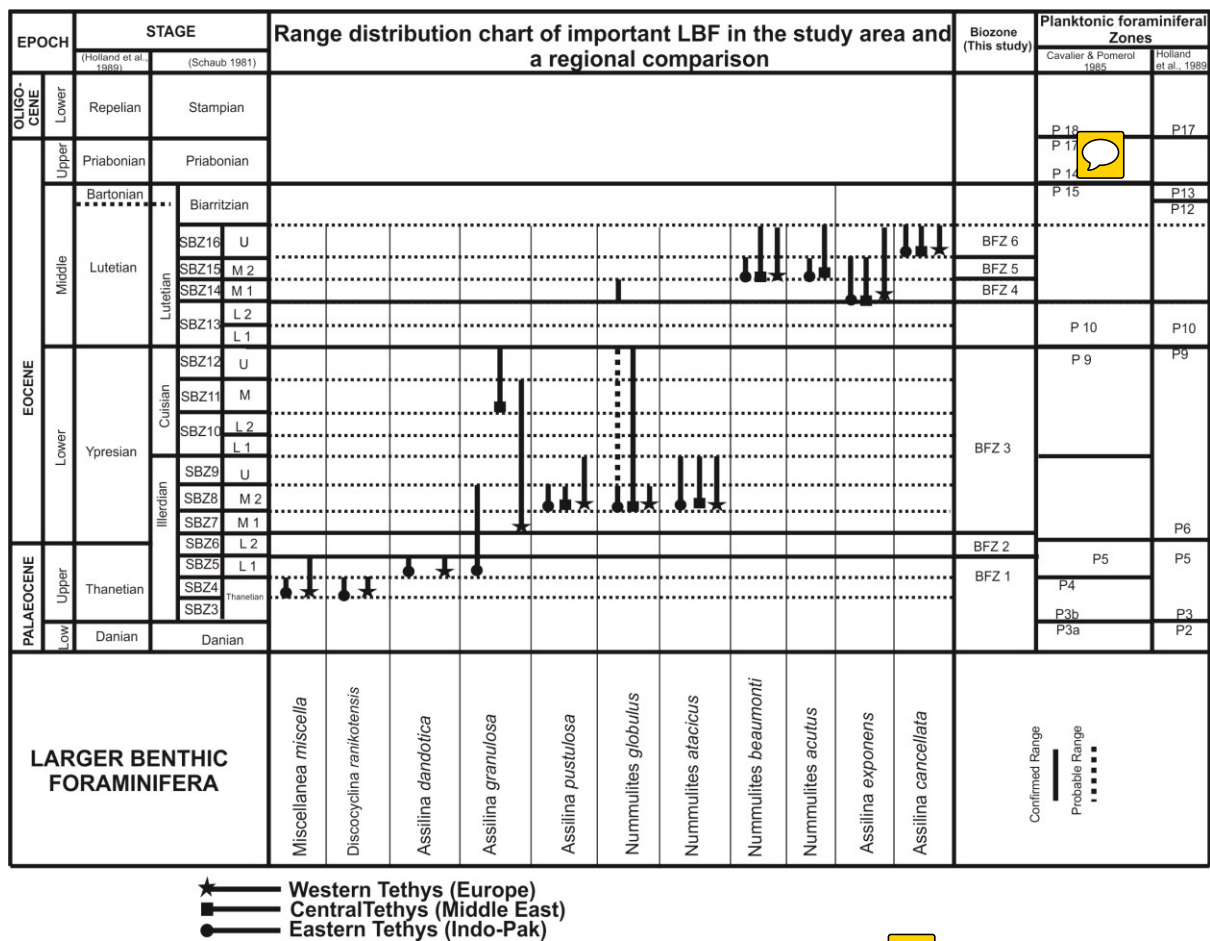


Fig 7. The figure shows global first and last occurrences of the *Nummulitids* in the Eastern Tethys (Nuttal 1926; Davies and Pinfold, 1937; Eames, 1950, 1952; Gill 1953; Nagappa 1959; Pascoe 1963; Kureshy 1968; Sarkar 1968; Raju et al. 1970; Sing et al. 1970, Sahni and Kumar 1974; Samanta 1981; Murty 1983; Weiss et al, 1988; 1993, Jauhri and Agarwal 2001; Jauhri 2006; Govindon, 2003; Sameeni et al 1998, 2009; Mukhapadayay, 2003, 2005; Afzal 2009, 2011; Ahmad et al., 2014), Central Tethys (Bellen *et al.* 1959; Rahaghi, 1980; Kalantari, 1981; White, 1994; Racey, 1994, 1995; Karim and Bazainy, 2007), and Western Tethys (Schaub, 1981; Serra-Kiel *et al.*, 1998).

association with Nummulites and Alveolina in the Upper Zhepure Shale Formation representing Early Eocene (Cuisian≈SBZ 11-12). Based on the FO of *O. complanatus* in SBZ 11 (Serra-Kiel et al. 1998) and its regional distribution, it is concluded that F.O of *O. complanatus* is a useful biostratigraphic marker for the Early Eocene (Lower Cuisian 2-Middle Cuisian≈SBZ10-SBZ11) Boundary. The Middle Cuisian sediments are overlain by the terrestrial Koldana beds (Shah, 1977). Mammalian bones found at the base of Koldana Formation in the Kohat Basin (Gingerich, 2003) represent Early Eocene (upper Cuisian≈SBZ 12), which is in agreement with the LBF biostratigraphy of this study. There are no marine sediments found in the Potwar Basin after the Early Eocene (Middle Cuisian≈SBZ 11). In the Kohat Basin, however marine sediment accumulation occurred on top of the Koldana red beds following a new phase of marine transgression in the Middle Eocene (Middle Lutetian 1≈SBZ 14). This is indicated by the FO of the following nummulitid species: *A. exponens*, *A. spinosa*, and *A. papillata*. The FO of *A. exponens* (Schaub, 1981; Serra-Kiel et al. 1998) in BFZ4 Zone constrains the age of the first marine beds to the Middle Eocene (Middle Lutetian 1≈SBZ 14). Based on the common presence of *N. beaumonti*, *N. elliptica* and *N. acutus*, the BFZ 5 Zone partially correlates with the LFA 4 to 6 (Tertiary a3) in the Indian Basins (Govindon, 2003; Matsumaru & Sarma, 2010) and the Shallow benthic Zone; SBZ Zone 15 (Serra-Kiel et al. 1998). The literature review indicates that global FO of the *N. beaumonti* marks the Middle Eocene (Middle Lutetian1-Middle Lutetian 2≈SBZ14-SBZ15) Boundary (Fig 7). Other LBF species show a diachronous appearance within this zone and can be used only as local biostratigraphic markers (Fig 7). The BFZ 6 Zone is characterized by the F.O of *A. cancellata*. Based on the stratigraphic range of *A. cancellata* in Schaub (1981), the BFZ 6 Zone is representing Middle Eocene (Upper Lutetian≈SBZ16) age.

IMPLICATIONS FOR THE TIMING OF CLOSURE OF EASTERN TETHYS

Cessation of the marine sedimentation is one of the important approaches to date the timing of the India-Asia collision, resulting in the uplift of the Himalayas (for overviews see Najman et al. 2010). We follow this approach, and we use the new LBF biostratigraphy to provide evidence for the timing of the disappearance of the Tethys seaway in the Pakistan area as a result of Himalayan uplift. The disappearance of *A. davisie*, *A. pustulosa*, *N. atacicus*, and *O. complanatus* in the study area is similar to fauna in the ramp carbonates in the South-eastern Pyrenean Foreland Basin (NE Spain),

Western Tethys (Serra-Kiel et al. 2003). Although regression in the Kohat and Potwar Basin started earlier, but our biostratigraphic data suggest that a complete exposure of the basin took place around 50-49.5 Ma. This is the time of a global sea level fall in the Global Sea Level Charts of Haq et al (1987). The collisional tectonics played an important role in the restriction of the sea, but we suggest that the regression was most likely triggered by the global sea level fall around 50-49.5 Ma. The record of a rich LBF assemblage in BFZ 4 Zone shows that a renewed phase of marine sedimentation in the Kohat Basin began in the Middle Eocene (Middle Lutetian 1 \approx SBZ 14). Naggapa (1959) described the distribution of foraminiferal fauna and facies in Pakistan / India / Burma and concluded that the Kirthar Transgression (Kirthar was used as an equivalent to Middle Lutetian) was a major transgression covering India (Western Narbada Valley, South of Combay, Cutch, Aasam), Pakistan (Sind, Baluchistan, Kohat and Potwar), Burma (Anarkan, Andamans) and whole of Indonesia. The Lutetian transgression, where a dozen of identical species of Nummulites have been found in the Alps and in the Himalaya during the Lutetian, mainly indicating that the transgression was not only continuous but isochronous intercontinentally (Sarkar, 1967). The deposition of the middle Lutetian 1 carbonates in the Kohat Basin (\approx BFZ 4 Zone) can be correlated with the eustatic sea level rise in the TEJAS A TA 3 stratigraphic cycle in the Global Sea Level Charts of Haq et al. (1987). We can only speculate why renewed flooding occurred in the Kohat Basin, possibly caused by a combination of flexural loading of the Indian plate (Pivnik & Wells 1996) and/or eustatic sea-level rise (e.g. Haq et al. 1987).

The biostratigraphic range of *A. cancellata* (Schaub 1981) along with associated nummulitid species in the Kohat Basin constrains the age of the final disappearance of the eastern Tethys seaway in Pakistan, which occurred during the Middle Eocene (Upper Lutetian \approx BFZ 6 Zone,) around 41.2 Ma.

SUMMARY AND CONCLUSIONS

The Paleogene LBF study of the Kohat and Potwar Basins of northwestern Pakistan, representing the Eastern Tethys, is documented. The recorded LBF include *M. miscella*, *R. sindensis*, *D. ranikotensis*, *L. haimie*, *L. conica*, *A. dandotica*, *Al. globula*, *N. globulus*, *N. atacicus*, *N. pinfoldi*, *A. spinosa*, *Al. pasticillata*, *O. complanatus*, *A. exponens*, *A. laminosa*, *N. beaumont*, *A. papillata*, *A. cancellata*, *A.*

granulosa, *A. pustulosa*, *Al. cucumiformis*, *Al. elliptica*, *Operculina* sp, *R. sahni*, *A. daviesi*, *A. sutri*, and *N. acutus*.

The biometric features and coiling graphs of the nummulitids are presented and compared with specimens, mostly from the Eastern (Mukhopadhyay 2003) and Western Tethys (Schaub 1981). This appeared useful for selection species helpful for local and regional biostratigraphic correlation. Six local Zones (BFZ 1-6) representing Late Paleocene (Thanetian)-Middle Eocene (Upper Lutetian) are established in the Kohat Basin. The first three Zone (BFZ 1-3) representing Late Paleocene (Thanetian)-Early Eocene (Middle Cuisian) are found in the Potwar Basin and TIR. All Zones are compared with previously established local and regional LBF biostratigraphy schemes. It is concluded that disappearance of *M. miscella* and *R. sindensis* and F.O of *A. dandotica* coincide with the Late Paleocene (Thanetian≈SBZ4) and Early Eocene (Lower Illeridian 1) Boundary. In the BFZ 2 Zone, *A. pustulosa*, *Al. vredenburgi* (*Cucumiformis*), *Al. globula* and *Al. pasticillata* represents Early Eocene (Lower Illeridian 1-Middle Illeridian 1≈SBZ5-SBZ7). The FO of *N. atcicus*/*N. globulus* and *O. complanatus* (Serra-Kiel et al 1998) in the BFZ 3 Zone is useful for constraining the Early Eocene (Lower Illeridian 1-Middle Cuisian ≈SBZ8-11) age of sediments below the terrestrial Koldana beds. The record of BFZ 3 Zone indicates that cessation of marine sedimentation in the Kohat Basin and the Potwar Basin occurred around 50-49.5 Ma (BFZ 3 Zone≈SBZ11). This age provides constraint to the minimum age of the India-Asia collision. The FO of *A. exponens* and associated LBF species in the BFZ 4 marks the middle Lutetian 1 (BFZ 4 Zone≈SBZ11). The renewed flooding occurred only in the Kohat Basin around in Middle Lutetian 1 (BFZ 4). The FO of *N. beaumonti* in BFZ 5 Zone marks the Middle Lutetian 1-Middle Lutetian 2 Boundary (BFZ 5 Zone≈SBZ15). The final closure of the Kohat Basin, which marks the final presence the Tethyan seaway occurred around 41.2 Ma, in the Pakistan area ((BFZ 6 Zone≈SBZ16).). The cause of renewed local flooding remains speculative, probably caused by some form of local post collisional stress (after BFZ 3 Zone) and/or eustatic sea level rise (during BFZ 4 Zone). Based on the occurrence of LBF it is also concluded that youngest marine sediments in the Kohat Basin belong to Middle Eocene (Upper Lutetian) supporting the upper Kirthar (Late Middle Eocene) view of Davies (1940), Vredenburg (1906), Eames (1950,1952) and Roohi and Baqri (2004).

EXPLANATION OF PLATES

PLATE 1

1. Photomicrograph shows an axial view of *Miscellanea miscella* (MS) recorded from the Lockhart Formation in the Potwar Basin.
2. Photomicrograph shows an axial view of *Ranikothalia sindensis* (RA) recorded from the Patala Formation in the Potwar Basin.
3. Photomicrograph shows an axial view of *Discocyclus ranikotensis* (DSR) recorded from the Lockhart Formation in the Potwar Basin.
4. Photomicrograph shows an axial view of *Lockhartia haimei* (LOH) recorded from the Lockhart recorded from the Lockhart Formation in the Potwar Basin.
5. Photomicrograph shows an axial view of *Assilina dandotica* Davies (ASD) recorded from the Lockhart Formation in the Potwar Basin.
6. Photomicrograph shows an equatorial view of *Alveolina globula* (ALG) from the Sheikhan Formation in the Kohat Basin.
7. Photomicrograph shows an axial view of the *Nummulites globulus* Leymerie (NMG) and *Nummulites ataticus* Leymerie in the Sakessar Formation in the Trans Indus Ranges (TIR).
8. Photomicrograph shows an axial view of the *Nummulites globulus* Leymerie (NMG) in the Chorgali Formation in the eastern Salt Range area of Potwar Basin.

PLATE 2

1. Photomicrograph shows an axial view of the *Nummulites pinfoldi* Davies (NMP) in the Nammal Formation in the Trans Indus Ranges (TIR).
2. Photomicrograph shows an axial view of the *Assilina spinosa* Davies (ASP) and *Discocyclus ranikotensis* (DSR) in the Nammal Formation in the Trans Indus Ranges (TIR).
3. Photomicrograph shows flosculinized *Alveolina pasticillata* (ALP) in the Sheikhan Formation, Kohat Basin.
4. Photomicrograph shows *Orbitlites complanatus* (ORC) in the Sheikhan Formation, Kohat Basin.

5. Photomicrograph shows an axial view of *Assilina exponens* Nuttal (ASE) and *Assilina laminosa* Gill (ASL) in the Kohat Formation, Kohat Basin.
6. Photomicrograph shows an axial view of *Nummulites beaumonti* d' Archiac & Haime (NMB) in the Kohat Formation, Kohat Basin.
7. Photomicrograph shows an axial view of *Assilina papillata* Nuttal (ASP) in the Kohat Formation, Kohat Basin.
8. Photomicrograph shows an axial view of *Assilina cancellata* Nuttal (ASC) in the Kohat Formation, Kohat Basin.

PLATE 3

List of age diagnostic LBF recorded in BFZ Zones in the study area.

Miscellanea miscella

1. (Axial section)

***Assilina dandotica* Davies & Pinfold**

2. Form B, partially exposing the equatorial section
3. Form B, axial section

***Assilina granulosa* d' Archiac & Haime**

4. Form B, equatorial section
5. Form B, axial section
6. Form A, equatorial section
7. Form A, axial section

***Assilina pustulosa* Doncieux**

8. Form B, equatorial section
9. Form B, axial section
10. Form A, axial section

***Nummulites atacicus* Leymerie**

11. Form B, axial section
12. Form B, equatorial section

13. Form A, equatorial section

14. Form A, axial section

Nummulites *globulus* Leymerie

15. Form B, equatorial section

16. Form B, axial section

17. Form A, equatorial section

18. Form A, axial section

Alveolina *cucumiformis*

19. Unfloresculed specimen

20. Axial section

Alveolina *globula*

21. Equatorial section

Alveolina *pasticilata*

22. Equatorial section

Alveolina *elliptica*

23. Axial section

24. Oval shaped, double protoconch

Nummulites *beaumonti* d' Archiac & Haime

25. Form B, equatorial section

26. Form B, axial section

27. Form A, equatorial section

28. Form A, axial section

Assilina *exponens* Sowerby

29. Form B, equatorial section

30. Form B, axial section

31. Form A, equatorial section

32. Form A, axial section

***Assilina cancellata* Nuttal**

- 33. Form B, equatorial section
- 34. Form B, axial section
- 35. Form A, equatorial section
- 36. Form A, axial section

PLATE 4

The list of associated LBF in the BFZ Zones of the study area.

- 1. ***Ranikothalia sindensis*** (axial section)
- 2. ***Operculina* sp.** (off centered axial section)
- 3. ***Discocyclina ranikotensis*** (axial section)
- 4. ***Ranikothalia sahni*** (axial section)
- 5. ***Lockhartia haimei*** (axial section)
- 6. ***Lockhartia conica*** (axial section)

***Nummulites pinfoldi* Davies**

- 7. Form B, equatorial section
- 8. Form B, axial section
- 9. Form A, equatorial section
- 10. Form A, axial section

***Assilina davisie* de Cizancourt**

- 11. Form B, equatorial section
- 12. Form B, axial section
- 13. Form A, equatorial section
- 14. Form A, axial section

***Assilina spinosa* Davies**

- 15. Form B, equatorial section
- 16. Form B, axial section
- 17. Form A, equatorial section
- 18. Form A, axial section

***Assilina papillata* Nuttal**

19. Form B, equatorial section

20. Form B, axial section

21. Form A, equatorial section

22. Form A, axial section

***Assilina laminosa* Gill**

23. Form B, equatorial section

24. Form B, axial section

25. Form A, equatorial section

26. Form A, axial section

***Assilina sutri* Schaub**

27. Form B, axial section

28. Form B, axial section

***Nummulites acutus* Sowerby**

29. Form B, equatorial section

30. Form B, axial section

31. Form A, equatorial section

32. Form A, axial section

PLATE 1

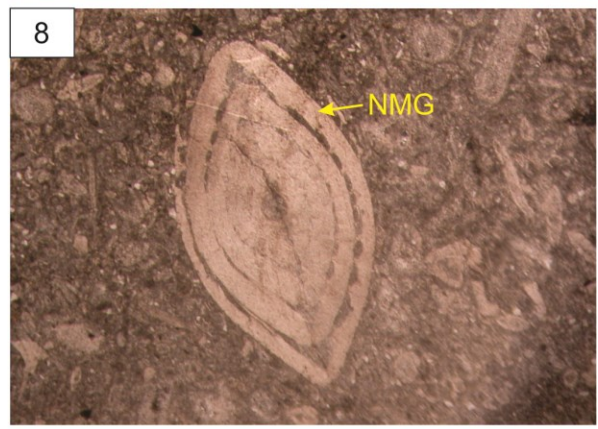
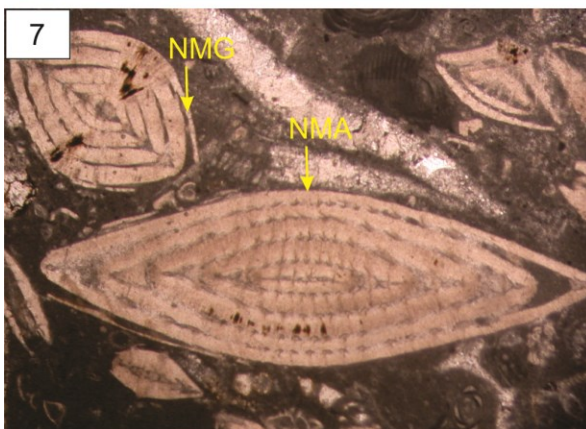
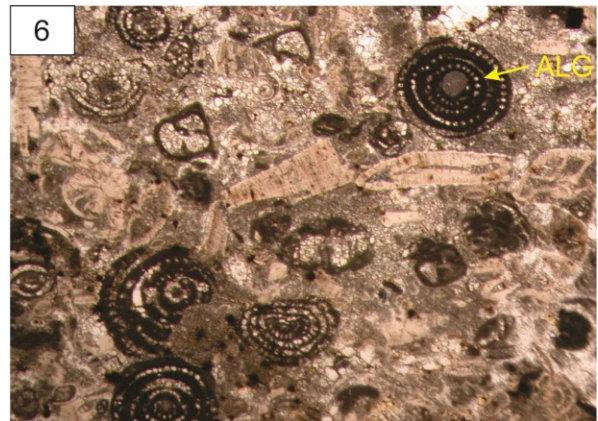
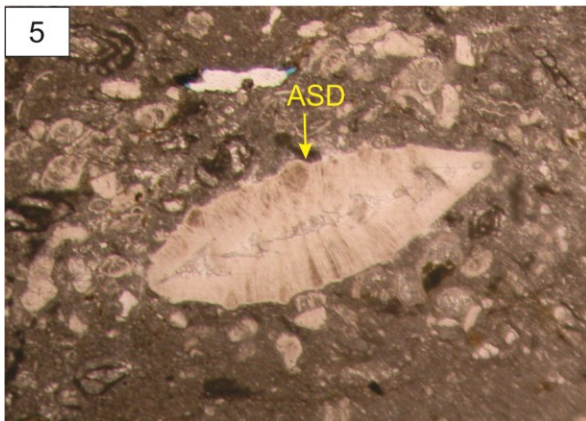
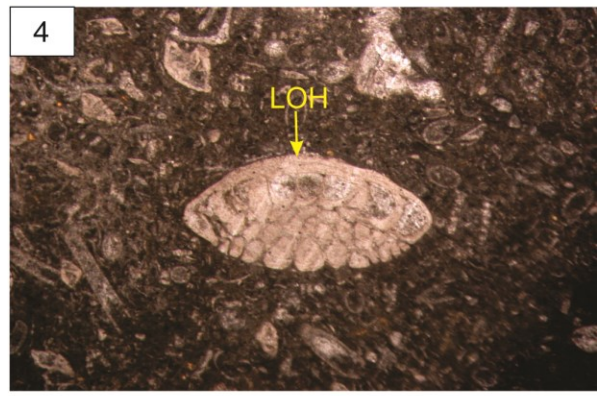
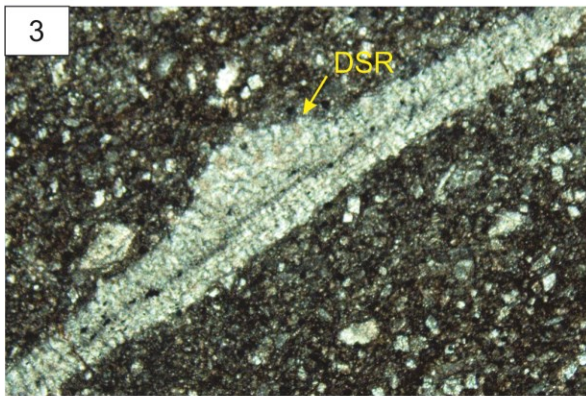
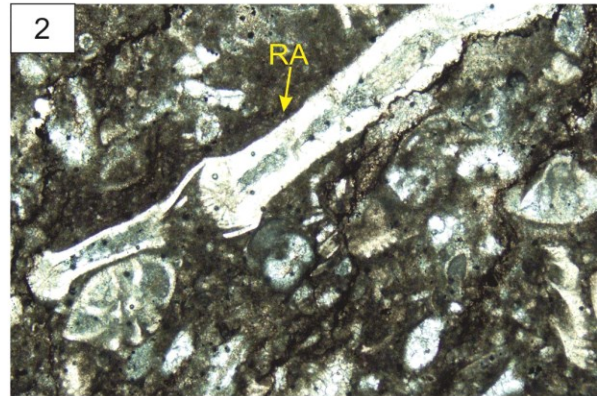
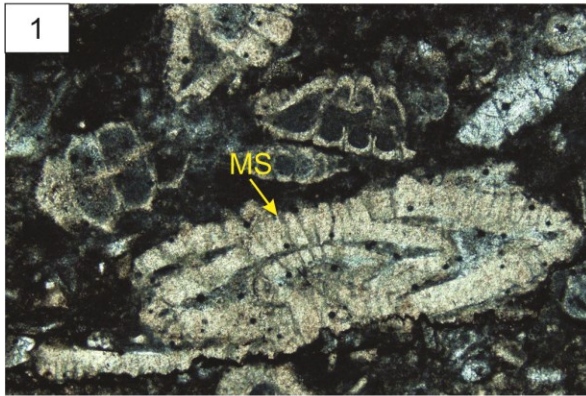


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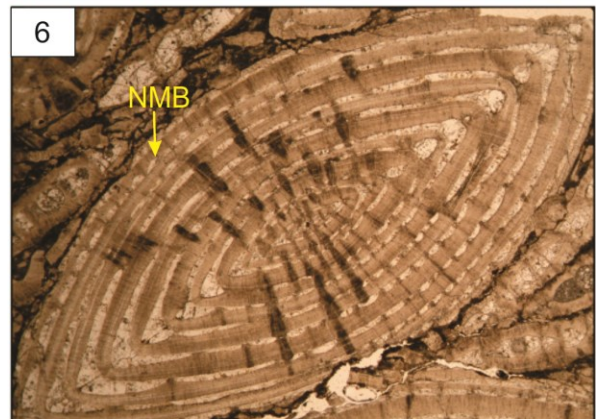
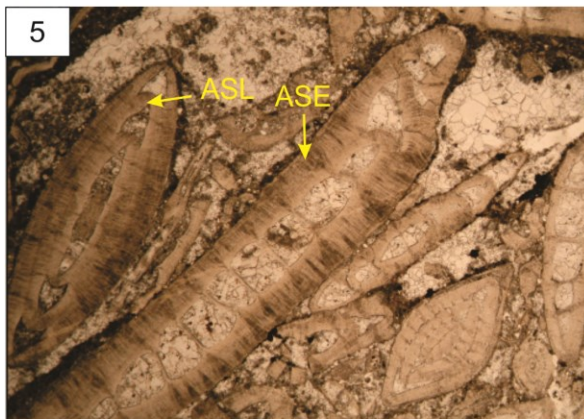
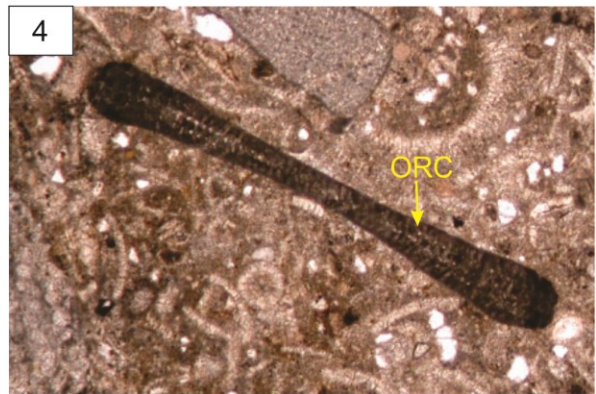
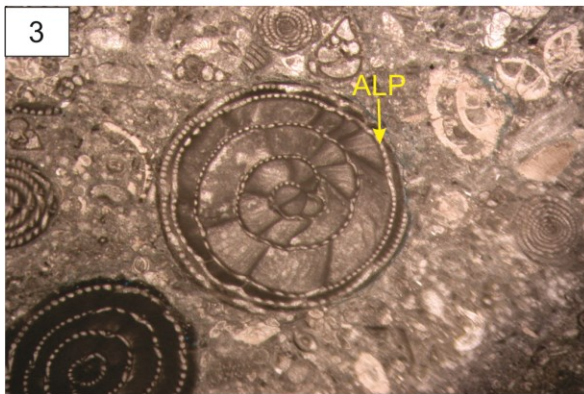
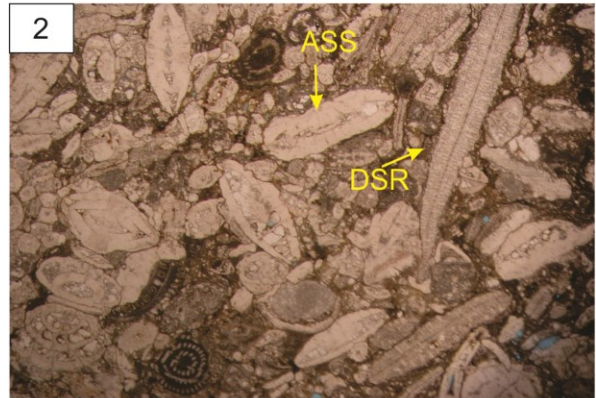
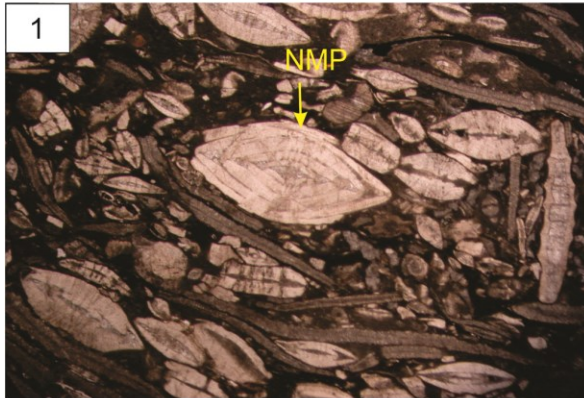


PLATE 3

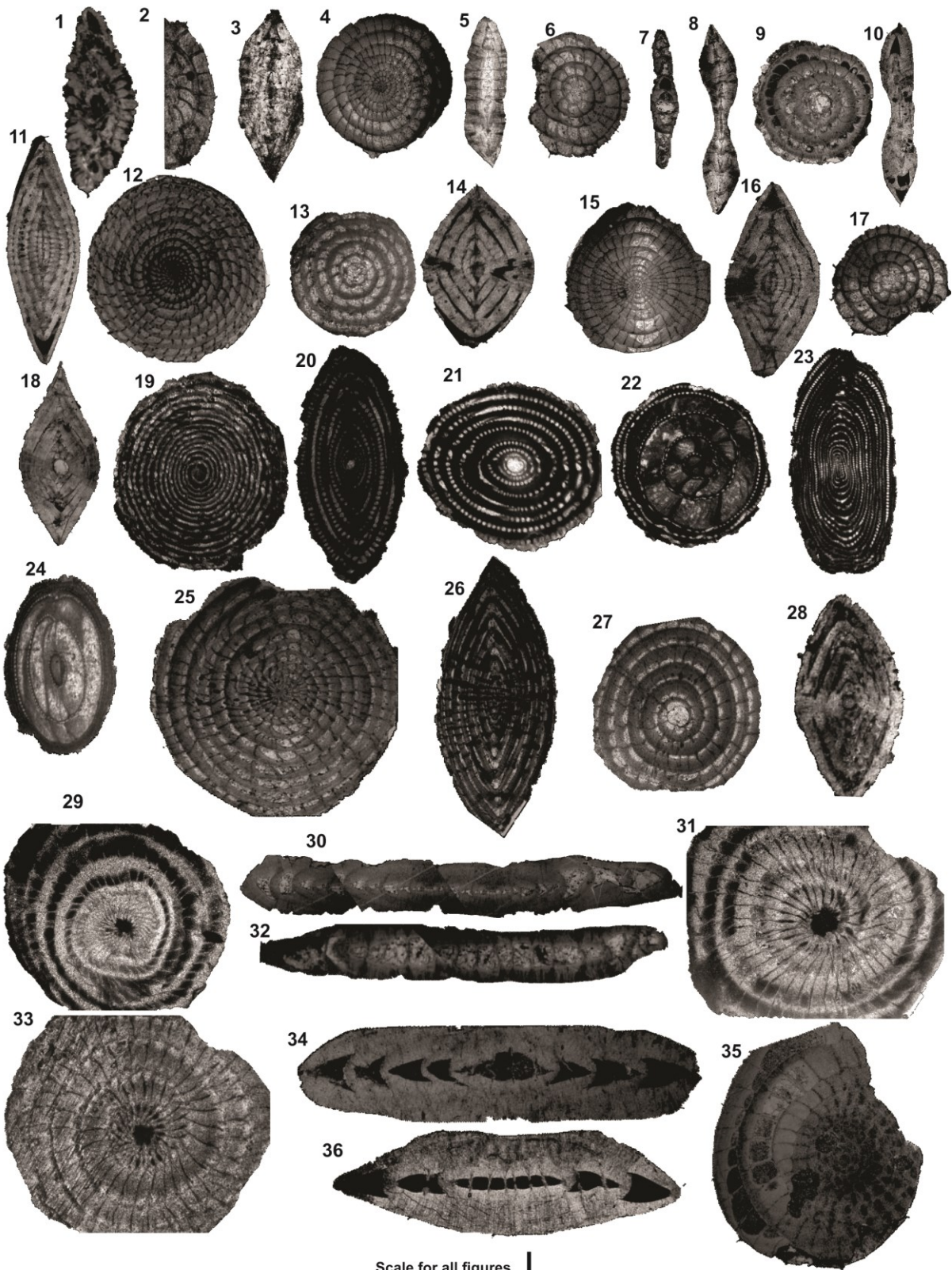


PLATE 4



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